SPEECH AND VOICE

G. OSCAR RUSSELL

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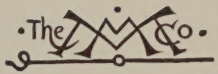

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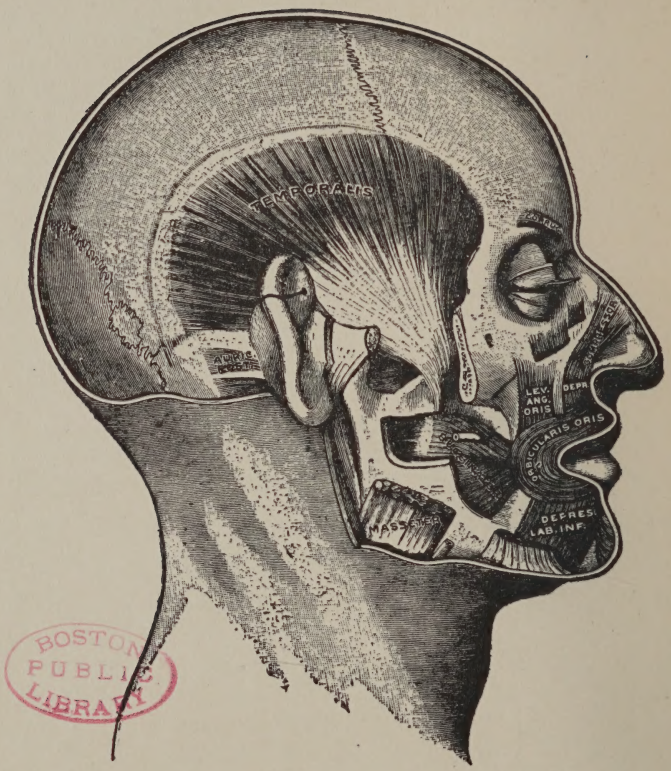

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THE PRINCIPAL EXTERIOR OR FACIAL MUSCLES INVOLVED IN SPEECH AND EMOTIONAL EXPRESSION OF THOUGHT. (Gerrish)

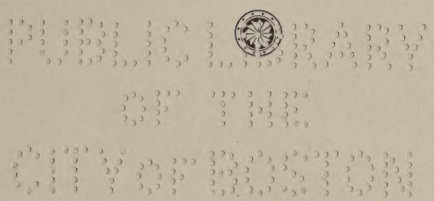
SPEECH AND VOICE

With X-Rays of
English, French, German, Italian, Spanish,
Soprano, Tenor, and Baritone Subjects

BY

G. OSCAR RUSSELL, PH.D.

DIRECTOR OF PHONETICS LABORATORIES
AND SPEECH CLINIC, OHIO STATE UNIVERSITY



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DEDICADO

a los amiguitos españoles de mi juventud en el
pueblecito de Conejos, donde nací y
pasé toda la vida preparatoria a la del hombre serio;

a esos pícaros amables que con su burla de la pronunciación
típico de los "gringos" ambulantes,
iniciaron en mí
lo que resultó el primer estímulo a los estudios científicos
de la fonética.

JORGE O. R. DE C.

PREFACE

This volume has been assembled for the primary purpose of presenting a comprehensive series of speech and voice cavity X-rays, together with a laryngo-periskopik study of vocal cord and interior laryngeal function. The two studies combined thus cover the entire mechanism involved in creating speech and voice quality differences.

The X-ray photographs show the exact median line in sagittal section (*i.e.* perpendicular cut) of the vocal tract, from the glottis, or point where the sound originates, to its exit. They delineate the position of the tongue and other vocal organs in free unhindered normal function. The subjects include: old and young, from small children to those in the prime of manhood and toothless old age; male and female; English, French, German, Italian, and Spanish; Soprano, Tenor, and Baritone singers, all having trained voices and recognized ability.

It is the first such study to be made by way of scientific experiment, in an attempt to analyze and fix the facts involved in the physiological cause of speech and voice quality differences. As such it has its faults. The facts presented in the experiments and cuts herein, represent the real contribution, so they must needs be given careful study, and that time and again. They need to be analyzed in an organized way.

Part of this volume is designed to be practical, as the title thereto indicates. And it is presented in such a way that he who runs may understand. Such are the chapters for *teachers of the deaf*, the chapter for *teachers and students of the singing and speaking voice*, and the more scattered ones for *philologists* or *linguistic scholars*, and for *students and teachers of English, French, German, Italian, and Spanish.* The chapter for teachers of the deaf attempts to organize and study the material of the X-rays in the manner the author as a teacher would have students of his in any of the other fields do. And he believes those who do so will be amply repaid.

But after all, the experimental evidence represents the real contribution. And the author is grateful for the recognition given his X-ray

experiments by scientists, especially those abroad, who have been so generous in their comment on the way in which he has succeeded in controlling the sources of error, the checks thereon provided, the scope of facts portrayed in the experiments themselves, and the new proof brought to bear on the long debated and still debatable questions as to what the physiological causes of speech and voice quality differences are. The technique used is for the most part responsible. It took years to develop, and yet it is now simple enough so that individuals from California to New York with no experience whatever in the field have undertaken on their own responsibility to start out along the same line, oriented solely by what passing friendly confidences they could gain verbally. Nevertheless, the X-ray is still no plaything and is dangerous. And it is not likely that a comprehensive study including over 400 subjects and 3000 experiments from which those herein are chosen, will be undertaken again in the near future. Nor can any reliable conclusions be justifiably drawn where there are involved only a handful of subjects, a limited group of vowels, and sources of error which are not controlled from every possible angle.

Then too, the publishers have been extremely liberal in permitting the insertion herein of the most comprehensive anatomical speech and voice organ charts which the author has ever seen in any work dealing with the subject. Perhaps, therefore, he may be pardoned the hope that this volume may be found to offer a real contribution in this field of science — one which will long hence still be considered basic enough to justify careful examination.

In closing he takes the opportunity of expressing indebtedness to his publishers; to those who preceded him in the field and others to whom references are made in notes and text; to the Graduate Council and Dean William McPherson, to whose financial aid and warm sympathy so much is due; to President George W. Rightmire, Assistant George W. Eckelberry, Deans Walter J. Shepard and George F. Arps, of Ohio State University, whose hearty encouragement of his research specialization within the field has placed the author under profound obligation; to Caperton Horsley, one of the most brilliant engineers the author has known, who gave so freely of his time in the solution of so many vexing X-ray and sound recording problems; and to his friends, Dean C. E. Seashore, and Drs. E. W. Scripture, Harvey Fletcher, M. A. Goldstein,

Robert Rockwood, Harris Taylor, Hugh Means, Elmer L. Kenyon, Max Meyer, G. Panconcelli-Calzia, E. H. Sturtevant, H. B. Williams, T. Navarro Tomas, and E. A. Meyer, the author expresses grateful acknowledgment for an indebtedness they will permit him thus cursorily to acknowledge.

G. O. R.

COLUMBUS, OHIO
Christmas, 1930

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tones similarly produced. So piercing, strident, quality. Like cough. Glottal stop. Used by German school instead of García's much misunderstood "stroke of the glottis." Stridency-clashing brass-like quality. Unmusical. Mucus injects excessive inharmonic partials. Interior tension indication one set muscles pulling against another. Nature balks. Voice breaks. Sob. Voice catches. Stammerers. Emotional tension creates transitory situation in best of artists. Untrue pitch. Overly tired. Mere warning. Panic unwise.

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SOUND SYMBOLS USED IN THE TEXT

English Current Spelling	Yale Symbols	Phonetic Symbols	As in American English	Spanish	French	German
ee	(ee)	*i*	see, beef, mach*i*ne	sí	si	sie
	(–i–)	ɪ	sit, bib, kick			b*i*tte
ey	(a–e)	*e*	they, fame, cake	sé	ses	see
eh	(–e–)	ɛ	set, pep, keg			bett
	(–a–)	æ	sat, map, gag			
ah	(ah)	*a*	psalm, mop, cock, f*a*ther	la	âme	bat
aw	(aw)	ɔ	salt, caulk, bawl		robe	s*o*nne
uh	(–u–)	ə	tush, muff, id*ea*, th*e*		le	gab*e*
oh	(o–e)	*o*	tone, foam, coke, lo	lo	rose	mohn
	(o^2o)	*ʊ*	soot, cook, foot			
oo	(o^1o)	*u*	tool, boob, moon	su	rouge	mut
	Yale symbols represent the sound in conventional English spelling. The dash (–) stands for a consonant.	*y*			culte	müde
		ʏ				Mütter
		~~ɵ~~			jeudi	möbel
		œ				wölben
		j	*y*es, on*i*on, bil*i*ous		*y*eux	*j*a

NOTE: It will be obvious to linguistic scientists, that the above represents a very broad transcription. "Ah" is substituted for the Yale *a(r)*. And the ʌ and ə are grouped under ə. Most of the phonetic symbols are as old as those of chemistry and as widely accepted and understood among scientists the world over.

PART ONE

SCIENTIFIC ASPECTS

CHAPTER I

INTRODUCTION

Nearly all theories which have been advanced to account for differences in voice quality have been based upon the analyses of speech sounds after they have left the mouth. These analyses are themselves founded upon hypotheses; yet upon the basis of the results thus obtained it has been common to postulate further theories to explain these differences physiologically. For a hundred years a way out of all the resulting confusion has been sought, but this has generally been done by following in the same well-worn path. The attitude of scholars so engaged and the justification advanced by them for their theories have not deviated radically, and do not deviate radically even today, from that stated by Willis, who began the vowel study technique still used — though with modifications, and of course, with inevitable perfections, due largely to present more modern equipment. In his words:[1]

> "The vowels are mere affections of sound, which are not at all beyond the reach of human imitation in many ways, and not inseparably connected with the human organs, although they are most perfectly produced by them; just so, musical notes are formed in the larynx in the highest possible purity and perfection, and our best musical instruments offer mere humble imitations of them; *but who ever dreamed of seeking from the larynx an explanation of the laws by which musical notes are governed.* These considerations induced me, upon entering on this investigation, to lay down a different plan of operation; namely, *neglecting entirely the organs of speech, to determine*, if possible, by experiments upon the usual acoustical instruments, *what forms of cavities* or other conditions *are essential* to the production of these sounds, after which, by *comparing these with the various positions of the human organs*, it might be possible, not only to *deduce the explanation and reason* of their various positions, but to separate those parts and motions which are destined for the performance of their other functions, from those which are immediately peculiar to speech (if such exist)."[2]

[1] Willis. "On Vowel Sounds, and on Reed-organ Pipes." *Trans. Camb. Phil. Soc.*, III (1830), 231 f.; also in *Ann. d. Phys. u. Chem.*, XXIV (1832), 397.

[2] Italics are mine. — AUTHOR.

If it had been possible to ascertain the exact " positions of the human organs " to which Willis refers so much disagreement might not have resulted; since instead of observing and analyzing the one series of facts and guessing at the others (which too often were made to fit some preconceived theory) the ascertained *facts pertaining to both speech production, cause, and effect might have been compared and thereby less disputable theories arrived at.*

The ideal study would combine and synchronize both the physical and physiological. But since innumerable physical studies have been and are still being made, giving rise to such theories as the air-volume-cavity-tone-resonance vowel and voice-quality theory, requiring primarily physiological study, the first attack must needs be physiological. The combined study can then follow.

This is the purpose of the present investigation. We propose to ascertain the forms and sizes of our speech and singing cavities; also the position and relative relationship of the various physiological organs as they actually appear when producing certain speaking and singing resultants — rather than merely to guess at them, or to postulate what they should be in order to conform to given theories and sound wave analyses; or in other words, rather than to state them as we imagine them to be, judged by our own subjective feeling as to what each one of us personally thinks he feels in the course of his own production. For as we know, all of these feelings vary radically in different individuals. Each one imagines or thinks he feels precisely what his theory leads him to expect. The resulting confusion is well known. A student of voice is first told to do one thing; then when he changes teachers months and years are often spent to undo what the other teacher taught, with a resulting loss to the world of millions of dollars. Among philologists, students of foreign languages, physicists, psychologists, and other such scholars the need for known physiological facts to take the place of present unsupported theory is quite as apparent. To provide such physiological fact this study is therefore undertaken.

CHAPTER II

THESE X-RAY EXPERIMENTS

The X-ray uncovers secrets for us which have been hidden from the beginning of time. It makes it possible for us to look right through walls of opaque material which ordinarily prevent us from seeing the drama being enacted behind.

Its penetrating power varies with the density of the substances it must pass through. Its rays are more or less blocked by any particle made of lead — one of our heaviest or densest metals. Yet they pass through a wall of flesh with comparative ease; and when they meet a bony surface they encounter a substance more difficult to penetrate than flesh, but less opaque to their transit than lead.

This property makes the ray all the more valuable to us. Because a photographic film placed behind a body consisting of a composite of densities will show a deposit representing a variation of lights and shadows when the X-rays are thrown against it; that is, it will come out of the developer looking very much like any other photographic negative we have come to know. When a print is made from this negative the denser bony surfaces will show black, the cartilages a somewhat lighter color, and the fleshy and muscular surfaces a still vaguer gray.

New Aspects of Present Study

Analysis of Cavity-Tone Theories. The X-ray experiments contained herein are the first to be published which bear directly on the physiological problems involved in the resonance and cavity tone theories, or if you will, in the basic theories explanatory of speech and voice. For the first time, too, a sufficient number of subjects, with full sets of vowels for each, are given to justify the drawing of definite conclusions. One subject is not enough. Neither are one or two vowels from four or five subjects. And the meagre attempts which have thus far appeared have been so limited.

Preparation of Pictures. The cuts published herein have also been so prepared as to serve all readers. The walls of the cavity have in each case been carefully outlined so that they will show just as clearly and unmistakably in the printed cut for the reader as they do in the negative for the author. And care has been taken to outline nothing which was not definitely shown on the negative. The process thus used assures an accuracy which is infinitely greater than anything heretofore attempted, for the error in no case can amount to more than the fraction of a milli-

meter. As a result, each experiment is so presented in the cuts published herewith as to make possible exact computation of its cavity dimensions by any reader, and that along the median or center line of the tongue showing the real cavity in its widest opening. After all, this is the absolute *sine qua non* in any X-ray experiment which is to be used in seeking information pertaining to the most widely accepted basic vowel theories, especially the resonance or cavity-tone theories. It is one of the reasons why a non-marker technique, like that of Scheier, recording only the misleading edges of the tongue, is of no value to us.

Simultaneous Phonograph Record. Then too, a phonographic record, synchronized so as to record nothing but the sound produced during exposure, was made simultaneously along with the X-ray exposure. This has made possible a check-back on acoustic control, never before attempted, and it makes sure that the tongue position photographed represents the vowel designated.

Voice Pitch Controlled. The glottal pitch was kept as constant as possible by prolonging its pitch in the ear of the subject, generally, unless otherwise indicated, at 100 d.v./sec. or at about the second A below middle C.

X-Ray Amplifications Kept Constant. The amplification of the median line was also for the first time so controlled as to make all negatives strictly comparative.

Necessity Thereof. All of these controls would seem to be absolutely necessary in any specific study of speech and voice theories, but they have not been exercised in the limited X-ray studies heretofore published. In this sense, if in no other, the author has cherished the hope that his experiments may be found to make some contribution. If his interpretation is wrong, the experiments themselves still remain, and are so presented as to be usable by all. After all, it is of little consequence whether any theory he has presented is right or wrong. The experiments contain the facts. And it is facts we seek.

Why an X-Ray Study

For over a hundred years scientists have been seeking an answer to the question: "*How do we talk; how do we produce those subtle differences which distinguish our different vowels; what makes the infinite variety of quality heard in the innumerable singing and speaking voices, no two of*

which are alike?" But to date, the most careful have had to answer, "We know so little that we cannot agree."

Previous X-Rays. Hundreds of attempts have been made to utilize the X-rays in seeking an answer. Yet no one investigator has published more than four or five such experiments made on more than one subject. And none of these meagre few which have appeared makes it possible actually to measure the vowel cavity itself in median section alone, much less check on the other mass of facts which need to be known in order to arrive at any adequate answer. None of them shows the upper back part of the vowel cavity wall, known as the velum. And hence the dimensions of this most vital part of the cavity are left an unknown quantity. Most of them use no median marker, and so show nothing but the curved edges of the tongue; and the center line or point of widest opening is not indicated. The tongue positions they do give may therefore be seriously misleading. For after all any vowel theory is more concerned with the center line than with the side line, and in every way the position taken by the edges of the tongue is of far less importance than is that of the center line. Besides, these two lines as indications of cavity size — that is, the edges line and the median line — may differ radically, as will be seen in Figs. 48–68, 84–86, 111, 123, 124, 136, 166, 167, etc. (The curved-up edges are dotted in the experiment, and the center shows in the unbroken white line.) Therefore in spite of the great contributions made by Barth, Eijkman, Meyer, and Scheier, to name the principal scholars who have each published a limited few experiments, one would seem to be justified in saying that the X-ray has thus far yielded but little positive information which may be used in a definite answer to the question above posed. Such at least was the statement of Henry Sweet in his 1910 second edition of *Sounds of English* (p. 107).

> "More may be seen with the Röntgen rays, whose use, however, is attended by some drawbacks — such as loss of hair, and the necessity of having the back teeth drawn — *the results hitherto obtained being too vague to be of much use.*"

Little New since Meyer. Since the appearance of Meyer's two X-ray photos in 1910, few others have been published; and with the exception of Stephen Jones' chain dropped down the nostril and over the palate, nothing new in the way of technique has been developed. Panconcelli-Calzia and his group generally used Scheier's non-marker process; and

for the most part others who have published anything have apparently produced negatives so vague that for purposes of publication they have had to resort to rather crude pencil tracings made upon the originals.

Content of Present Study. The author has spent something over eight years in perfecting an X-ray technique which would make some of this information in regard to the position of the vocal organs in speech available to all who care to utilize it. He has not seen fit to make any of his results public until he thought he had succeeded. But he now feels called upon to publish the best he has to date. Hence he submits the present study, which contains complete sets covering from ten to eighteen vowels for each one of a large number of individuals. These have been chosen indiscriminately from some four hundred odd subjects, and from over three thousand X-rays. The subjects include Spanish, Italian, English, French, and German natives; men, women, and children; old and young, varying in ages from eight to sixty-five years; a soprano, a tenor, and a baritone; and enough facts calling for interpretation to keep us busy for some time. If publication of the other studies ever appears to be called for, and funds are forthcoming, the remainder will be printed later.

CHAPTER III

PRELIMINARY EXPLANATION

"The most technical scientific experiment can be so presented as to be understandable and usable by the average intelligent lay reader. The secret lies in the proper preparation."

Masking Aids Lay Reader. The author has attempted to so present the experiments of this study as to facilitate the task of the non-technical reader, and at the same time retain all the essential information which the expert and scholar would desire to have at his disposal. It will be noticed that each of the X-ray pictures has been so masked as to make the unessential part stand out whiter than the area involved in the vowel cavity itself. Yet the masking has been so done that one versed in the highly technical reading of Röntgenograms will be able to follow clearly in this masked area the shadows of the harder bony surfaces and the various processes serving as points of muscular attachment. These, of course, are much more lightly shown than in the ordinary X-ray. But so long as they are visible, as is the case in a majority of the figures, the technician should not be disturbed, and the experiment is thereby made really to serve the average reader. For the latter's benefit it has been thought wise to include in this chapter, however, a short preliminary explanation.

What We Can See in Each X-Ray

Explanation of X-Ray Picture. The reading of such X-ray experiments as those presented in this study is a very simple task. As will be noted, the nose and mouth always face the left. This leaves the back part of the throat on the right, and the " Adam's apple " or larynx in the lower right-hand corner. Since the vocal sound which the singer produces, or the one which we utilize when we speak a vowel out loud, is created by the glottal lips or " vocal cords " located on the interior of the " Adam's apple," it follows that the vowel cavity begins in that lower right-hand

corner and ends at the lip opening, or mouth, on the left-hand side of each picture. As the surfaces which form the walls of this cavity are masked out somewhat so that they are whiter, it will be evident that the cavity itself is the darkest space in the central part of the picture. And as will be noted, this channel begins in the lower right-hand corner, extends upwards in each case for two or three inches, there makes an elbow like a stove-pipe, and then turns left from this generally perpendicular position to a horizontal one, where it runs another two or three inches and terminates at the lips on the left.

White Lines. In order that no reader may be misled, and that exact measurements may be made from any of the cuts submitted, care has first been taken to outline the walls of each vowel cavity. This is done by the white unbroken line, which, it is needless to say, is but an accentuation of lines shown clearly in the X-ray negative.[1] This line corresponds to the exact center of the vowel cavity along what the anatomist and physiologist would call the mid-dorsal or median, or what is sometimes referred to in this book as the sagittal section line. In all measurements of cavities, it is of course the outside edge of this line which is taken; for it is so drawn as to lie against the cavity wall line, so to speak.

Center Line of Cavity. The exact median line has been assured by a very thin marker. This is described in the chapters on technique. In most cases it was a specially prepared thread which the subject could not feel once it had been swallowed, and so made, that it adhered by capillary attraction to the center line of the tongue.

By reason of these continuous lines, the cavity is shown throughout at its point of widest opening; and any reader can measure at any point exactly what the dimensions of the cavity may be.

Raised Tongue Edges Shown. Sometimes the outside edges of the tongue curve up higher than the center. This is the case in Fig. 1 or Fig. 109. These edges have been shown by a dotted white line. The left edge of the tongue is always the vaguest and most enlarged or highest. This peculiarity is due to the target amplification shown in Fig. 2, and explained in the chapters on technique. The same enlargement is noticeable in one of the jaw bones (#3*b* in Fig. 1). That is, the left jaw is the vaguest, the most enlarged, and in this case the lowest.

[1] The reader who wishes to refer to an unmasked cut or one made from a negative in which no lines have been accentuated is referred to the stereographic X-rays in the author's *The Vowel*, published by the Ohio State University Press, Columbus, Ohio.

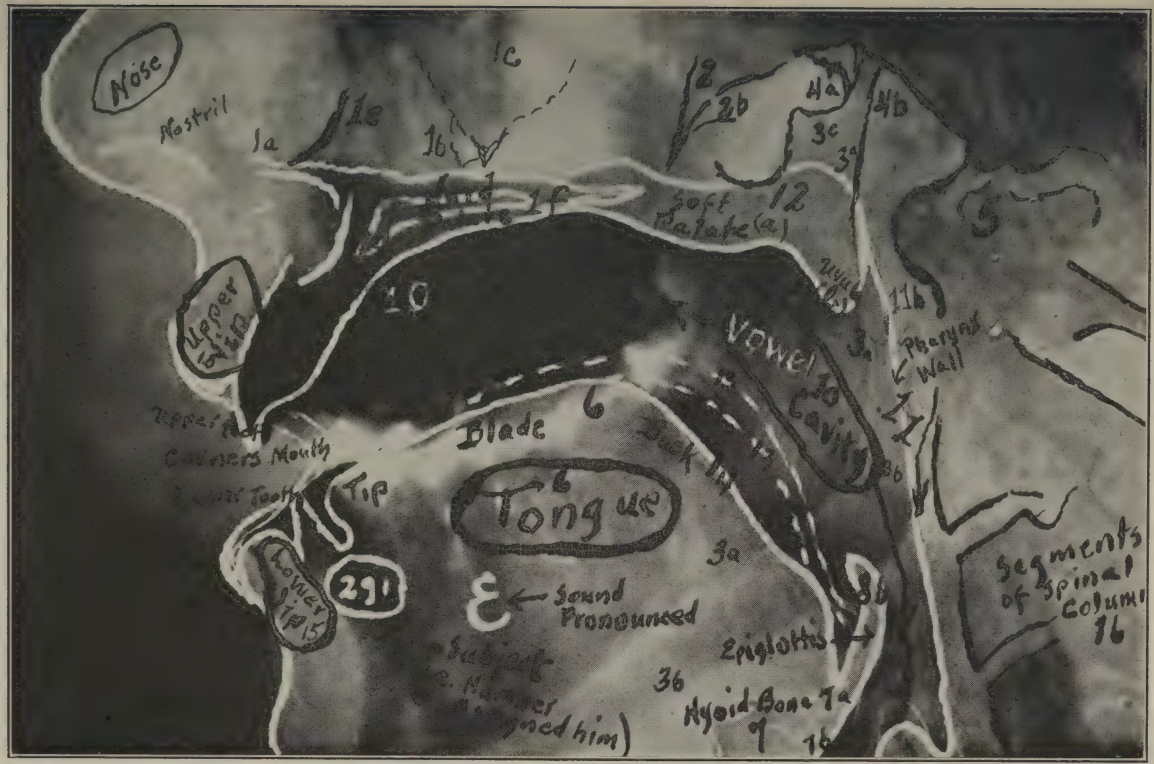


FIG. 1. — THE LAY READER MAY FIND OF SERVICE IN ORIENTING HIM THE ROUGH NOTES DRAWN ON THIS NATURAL SIZE ACTUAL X-RAY. THEY RECEIVE TEXTUAL COMMENT AND FURTHER EXPLANATION THROUGHOUT CHAPTER III.

Back Throat

Epiglottis. The little white tongue which sticks up in the lower right-hand corner is the epiglottis (#8*b* in Fig. 1). This is the trap door which was formerly supposed to serve merely in a physiological capacity; that is, its business was supposed to be that of " shutting off your Sunday

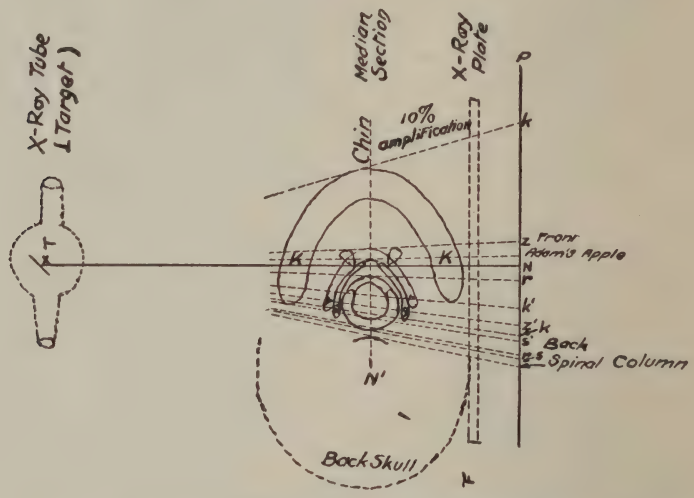


Fig. 2. — Showing Why All X-Rays Herein Are Amplified Along the Median Line $\frac{1}{10}$ More Than the Normal. The X-Ray Cuts Are All Reduced by $\frac{1}{2}$. So After the Reader Makes Any Dimension Measurement on the X-Ray Cuts He Should Double These and Deduct $\frac{1}{10}$.

throat " as we commonly say, and preventing the food from getting down inside the Adam's apple. As will be indicated in this study further on, it takes, however, such radically different positions for different vowels, as to justify the conclusion that it may serve a vital purpose in altering vowel quality. For this reason, and further, because we have not by tradition been accustomed to attribute any importance to it, the reader should perhaps observe its position more carefully than he normally would.

Back Larynx and Throat. Just back of the epiglottis will be seen one, and sometimes two, white humps (to the right of #7*b* in Fig. 1). This is the upper back part of the larynx or "Adam's apple." Technically it is the back horn, or superior cornu on each side of the thyroid cartilage.

Along this is attached a muscle called the stylo-pharyngeus, which leads up to a point of attachment spoken of as the styloid process (at #4*b* in Fig. 1) adjoining the hinge of the jaw bone opposite the ear. In some of these experiments this muscle to the right cornu, and to a lesser degree that to the left, is rather sharply delineated. Its line must not be mistaken for the center wall of the back throat or pharynx. These two horns, or back edge of the larynx, usually rest, one on either side, against the œsophagus, which lies just back of the larynx and is the tube which conducts the food down to the stomach.

Function of Epiglottis. When we swallow, the white tongue or epiglottis comes down and the larynx rises up against it to prevent the food from otherwise going down the wrong way into the lungs, or at best on to the vocal cords. Where this happens, coughing of course results, in order to expel the food from the larynx. This is the traditional view, which may now be at least in part questioned. The author's laryngo-periskop shows that in such cases the cushion of the epiglottis moving towards the cartilages of Wrisberg, along with the false cords, or other muscles on the interior of the larynx, also constrict above the vocal cords and thereby close the opening of the upper larynx. Since this observation is new the resultant conclusion may strike the reader as strange, viz.: the laryngo-periskop now leaves no doubt but what one of the principal functions of the epiglottis is to alter pitch and voice quality in speech and song. The reader should therefore study its changed positions carefully. And this especially in the light of the principles of physics applied herein for the first time.

Position of the Adam's Apple. Elsewhere the author has noted that the thyroid cartilage (or Adam's apple) seems to take decidedly different positions for different vowels. Since it has been thought to play such an important part in changing the pitch emitted by the glottal lips or "vocal cords,"[2] and since it may be vitally involved in altering the type of vibration or quality of the tone emitted, it will probably be well for the scholar and especially the student and teacher of singing to note carefully the relationship it holds to the hyoid bone (#7 in Fig. 1) and the vocal cavity above it.

Hyoid Bone. This hyoid bone looks in these X-rays much like the wishbone of a chicken, being more or less horizontal (though sometimes

[2] Russell, G. O. *The Vowel*, Ohio State University Press, Columbus, Ohio.

showing the prongs tipped upward on a radical angle — a variation which should be carefully studied). Its two prongs can usually be vaguely discerned extending towards the right almost to the segments of the spinal column (#16 on Fig. 1), showing there as two dark streaks about the width of a chicken's wishbone. The crotch will always be farthest left towards the chin, and where not clearly visible through the mask, will usually be dotted or outlined in white. This *hyoid bone* is attached to the chin or lower jaw at this point, by means of the *mylohyoid* and *geniohyoid* muscles; and it will be noted that these seem at times to be vitally involved in altering vocal quality and certain vowels — especially of course where the throat cavity at that point is radically distended, as in Figs. 156, 157, etc. One can note the tension in the *i* (of "pique" compared with *a* "palm") by placing the thumb under the chin and saying "ha, he" without moving the jaw; he may note this same tension also at times in the *u* of "sue" or "who" and in other vowels to a less extent.

Then too, the tongue is so intimately connected with the hyoid bone that any movement which the tongue itself makes as a whole body (disregarding, of course, those of the mere tip or front part) causes radical shifts in the hyoid.

The larynx is suspended from this hyoid bone and the epiglottis slides up and down just inside of it. It follows therefore that any movement of the tongue, particularly at the base, is certain to affect the hyoid bone, and through it, may well lead to a shift in the position of the thyroid cartilage. That is, a shift in the tongue position may mean a decided shift in the position of the larynx, and consequently where such a shift takes place, there is a possibility of this movement resulting in a radically different tonal quality in the glottal note. At least one may expect this to be true since the thyroid cartilage is so largely responsible for the tone produced by the glottal lips or "vocal cords."

Varying Throat Distension Important. It is therefore suggested that the reader observe carefully the changes in relative position which take place in these various parts of the vocal mechanism. The radical distension of the throat cavity at this point may have some vital bearing other than upon the resonance capacity which is apparent. That is, it may involve a possible function of the thyroid in accounting for some such differences as those manifest between Figs. 156 and 157, for example. These we need not discuss here.

Lack of Movement Sense in Throat Makes X-Ray Invaluable. We have felt it necessary to deal at length with the manifestations in the back cavity part of these X-rays, because up to the present time practically no information in regard to what is going on there has been made available. The sensations of movement, and the position of the muscular surfaces and vocal organs located in this area, are not such as to make it possible for us to subjectively analyze what is happening. We have no more power of sensing precisely what goes on in that part of our speech mechanism than we have in that of our heart function, or in the processes of our digestion. We cannot see this area during the production of normal unimpeded speech [3] or song, even with the aid of a laryngoscope or small mirror. Yet it is information we have long wanted to secure. More than one investigator has leaned to the view that vowel and voice quality might possibly be largely determined there, and some of the keenest of our phoneticians have expressed that idea. Among these was Jespersen, who in a comment of E. A. Meyer's plastographic measurements of the front tongue position, said: [4]

> "It is to be hoped that further investigations of the kind, already happily begun by E. A. Meyer, may shortly give us reliable information in regard to those points which still remain unclear, as for example pertaining to the function of the back tongue in vowel production, which perhaps in the end may be more important than the front tongue;" . . .

The author therefore feels that this study's principal contribution may well be sought in the experimental facts presented, dealing with the back throat or pharyngeal area. As most of such actual facts are probably made available for the first time the reader's attention is more specifically called thereto.

Front Mouth

Lips and Teeth. No reader will need a detailed description of what is to be seen on the X-ray pertaining to the front of the mouth. We daily

[3] The author's laryngo-periskop with which the photographs in Figs. 13–24 were taken does make that possible, and a few vowels can be checked on with other broncoscopes, phonoscopes, etc.

[4] Jespersen, O. His original Danish *Fonetik en systematisk fremstilling*, etc., or the 2nd German ed. *Lehrbuch d. Phonetik*, (Teubner Leipzig, 1913), p. 54, end of paragraph 4. My translation. "Es ist zu hoffen, dass weitere Untersuchungen derart, wie sie durch E. A. Meyer so schön eingeleitet worden sind, uns bald zuverlässige Auskunft geben werden über die Punkte, die noch im Unklaren liegen, so namentlich über das Verhalten der Hinterzunge bei der Vokalbildung, das vielleicht am Ende noch wichtiger ist als das der Vorderzunge;" . . . Other X-rays give some meagre pharyngeal information where the reader is expert enough to decipher their vague outlines; and this conforms, what there is of it, with the author's.

see this with our own eyes. The upper and lower lips (#15 in Fig. 1) are shown at the left of the photograph. The teeth are outlined in white at what would be the exact center interstice between the two large upper front teeth. That is, we see the X-ray exactly as if it had been a man's head sawed in two down the center line of the nose, between the two upper front teeth, through the dimple in the chin, and the point of the Adam's apple, and thence back.

Alveolar Ridge. Just back of the teeth there is a bump. If the reader who is unacquainted with the anatomy of his mouth will start the tip of his tongue at his teeth and move it up and backwards along the roof of his mouth as far as he can go, he will note, just beyond where it leaves his teeth, a point where his tongue passes over a hump and seems to shoot suddenly upwards. This bump is called the Alveolar Ridge. In the X-rays the curve is often somewhat accentuated so that it may not be missed even by the novice.

Hard Palate. From the Alveolar Ridge backwards we follow the hard palate whose bony surface is broken up by white islands in most of the X-ray pictures. This usually ends where the last jaw teeth do, but its cartilage extension may go somewhat beyond. Its projection into the soft palate is usually marked on the pictures herein. To it is attached the muscle which raises and lowers the uvula.

Soft Palate, Velum, Veil, or Palatine Arch. From here back the surface is soft. Most people can feel where this softness begins with the tip of the tongue, and if the mouth is opened and looked at with a mirror, it can be seen. This soft part of the mouth roof is called the soft palate or velum. A looking-glass will show the uninitiated that it ends in two veil-like fleshy arches, called the palatine arches.

Uvula. In the center between them, there projects downward a little flabby piece about the diameter of a pencil or of a girl's little finger. This is called the uvula. Under the author's technique, it is shown quite clearly as the downward projection of the soft palate (#12*b* in Fig. 1). Often it curves forward. It has its own little muscle attached to the cartilage extension of the hard palate mentioned above, and by many individuals it may thereby be raised or lowered. This seems to be especially true of professional singers who have trained themselves to pull it up out of the way, of certain girls or even women, and of some Italians, Spaniards, and other Romance language speaking peoples whose language

requires the production of ringing or bright qualities in given vowels, etc. The reader will note these various types in the X-ray photographs which follow. He need not be disturbed to find that the uvula is apparently sometimes missing; nor to discover that it takes different positions; nor to observe that the thickness of the soft palate varies even from vowel to vowel in the same individual; nor to note what a stiff, woodenlike position it takes in some persons.

Their Function When Raised. He might do well to study the position of both the uvula and the soft palate (velum) in relationship to the tongue, and pharyngeal walls in the light of what the author has said in his chapter on hard and soft surfaces. Where the uvula is raised and out of the way, it makes for what may be a *louder* tone, providing the whole cavity is wide open in a flare shape. If the glottal lips (vocal cords) coöperate to this end, and the tongue is simultaneously arched against the hard palate, its stiffness, and raising, will favor higher metallic partials in the tone by giving a "*bright*" type of sound (or even a "*metallic*" and possibly a "*shrieking*" or "*piercing*" one if carried to excess) in either the vowel, or the quality of voice of the speaker or singer. The muscular tension caused by excitement may be one reason why people who get angry manifest a "*strident*" quality in their voices; but the reader will of course take cognizance of the function of the interior larynx dealt with later on in accounting for this type of voice. (See Figs. 23 and 24.)

Function Lowered. The opposite effect is to be expected from those soft surfaces where the uvula hangs down and the palatine arches are relaxed. The tone will then be "*mellowed*" or it may even be "*deadened*" like the one produced when you "holler into the bung-hole of a barrel." This latter is particularly true where little space is left between it and the wall of the back throat or pharynx as these serve to enmesh the tone. Of course this enmeshing veil is really formed by the arches themselves. It is interesting to observe their play of tenseness and relaxation in certain trained singers, while one looks into their throats as they sing "ah" (*a*) in such a way as to shade into different tonal qualities. This fact has long been observed by singing teachers, as has also the raising of the uvula on high pitches — especially in the falsetto.[5]

The palatine arches consist of a pair of muscles on either side of the

[5] Recent X-ray photographs which the author has made of world-famous singers such as Bori, Gigli, Johnson, Melius, Althouse, *et al.*, throw doubt on the validity of this high-pitch palate and uvula raising.

throat, between which lie the tonsils. They are also called the pillars of the fauces or the anterior and posterior pillars. This whole area in the back part of the throat should be examined carefully for each experiment and studied in the light of the principles enunciated in the chapter on surfaces.

Nasality and Nasal Resonance. Before we leave this question we should not forget to observe that these X-rays seem to indicate that the opening of the nasal passage does not always result from a lowering of the velum (soft palate). It often happens that the subject pulls the uvula up as in Figs. 96 and 97 for example, and makes the opening into the nasal passages by a forward tension rather than a downward relaxation of the soft palate. The reader who is not a trained phonetician might also do well to remember that an opening into the nose does not necessarily mean nasality of tone. Most men with " resonant " bass voices speak practically all their vowels with the nasal passage open. It is only when the tone is penned in, in some sort of a *cul de sac*, that it turns out to be what is called " nasal " in quality. This penning in is regularly accomplished by the lips and tongue when we pronounce an *M*, *N*, or *NG*; by growths and the swelling of the turbinates as in colds; by certain constrictions in nasal muscles utilized especially by those with cleft palates; by an excessive constriction in the pharynx for certain " nasal twang " tones such as the one Sir Richard Paget cleverly imitates by laying the flat hand against the throat above the Adam's apple and pressing in forcibly; and finally (as shown by the author's laryngo-periskop) by a constriction between the cushion of the epiglottis, arytenoids, and false cords above the glottis.

CHAPTER IV

EXPLANATION OF SOME TERMS

"We often disagree merely because we fail to understand each other's terms alike."

Standard of Pitch. In this book where other authors are quoted, the standard of musical pitch used by them is often retained. On the other hand, where a comparison of two authors is necessary the pitches cited by one are sometimes converted, so that the two may be made to talk in exactly the same terms. Thus D. C. Miller prefers the tempered scale or so-called "International Pitch" where A = 435 and Middle C = 258.65; but Sir Richard Paget, and other scientific investigators cited in this work, generally use the "Physical" or "Scientific" pitch where A = 430 and Middle C = 256. Where the two are compared, the figures of the one are reduced to the norm used by the other.

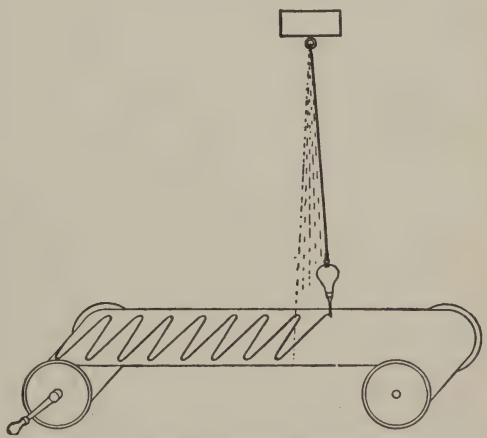


FIG. 3. — ONE COMPLETE SWING = 1 d.v.

Physical Pitch Used. In general, in this study itself, where nothing else is specified, "Physical Pitch" is used. For practical purposes, however, there is little difference between the two standards. Both were fixed on norms determined by Koenig, the Paris scientist and scientific instrument manufacturer who played such an important part in phonetic studies along about the middle of the last century.

Double Vibrations per Second = Pitch. Herein we usually use the term "d.v./sec." (double vibrations per second) in order to designate the frequency of a sound wave, or in other words, the pitch of a sound. We

thus revert to French practice, a common procedure even among physicists of this country. Let us explain: if it takes one second from the time a pendulum starts to swing until it reaches the other side and comes back again to the starting point we would count this as one "d.v./sec." That is to say, one double vibration represents one complete oscillation. If a pencil were attached to the tip of the pendulum, and if a piece of paper were drawn at a constant rate of speed, under it at right angles to its swing the pendular pencil would trace wave-like lines; and these from one crest to the other, or from one trough of the wave to the other would represent one double vibration.

Water Waves an Analogy. If we threw a cork out on the waves of a pond, it would rise and fall as they passed under it. Its ride from one crest until it dipped down and came up on top of the next would represent one d.v. and the number of such dips it made in a second would show the speed at which the wave was travelling. Hence the movement of the waves of the pond could also be represented in d.v./sec. If they made 100 such dips in a second, we would say the waves were travelling at the rate of 100 d.v./sec.

Sound Waves Like Balls, not Flat. It is a well-known fact that sound waves travel through the air in much the same manner as do the waves of

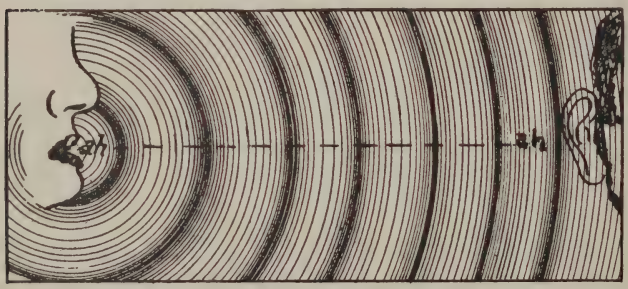


FIG. 4.—SOUND PROPAGATES IN ALTERATIONS OF CONDENSATION AND RAREFACTION.

a pond when a pebble is thrown into it; that is, they radiate in all directions from the point of stimulus. But unlike the pond waves, which are confined to one flat surface, they are transmitted up and down as well as along a horizontal plane. If we could see a series of sound waves at any given instant they would appear much like a series of progressively larger balls one outside the other (see Fig. 4), except that they would be made up of alternate layers of condensed and rarefied air, instead of rubber walls; and each would be spaced at an equal distance from the other.

Sound-Energy Not Air Motion. Of course in either case it is what the physicist calls the *energy* of the wave which travels, and not the medium itself. The cork out in the middle of the pond will bob up and down in the same place while the gently undulating waves pass under it; and the same particle of water will remain in the same place regardless of the waves which pass along — providing of course that no other factor such as churning, friction, capillary attraction, etc., is involved.

Like Shunting Car from Train. So in speech. Consequently, we must not lose sight of the fact that these vibrations we talk of are but energy vibrations. They are of the type of shocks we observe if we see an engine give a long string of freight cars a bump when the one farthest away is not coupled on but merely resting against the string; the train stays where it is, but the last car goes shooting down the track in consequence of the energy transmitted by the shock given the first car when the engine bumped into it.

Like Flipping Gelatin. Much the same thing happens in the vocal cavity it is constantly necessary for us to consider in this study. Since it is filled with air, composed of innumerable particles lying in close proximity to each other, it is of course much more like a mass of gelatin than a string of cars. But we all know what happens to such a gelatinous mass when it is confined in a pan and given a flip with the finger at any point. The shock is almost instantaneously shown throughout the mass; yet this is only indicated as a tremble or vibration, and no permanent distortion of the body itself results. If we so placed a recording needle that it would rise and fall with the vibrations which our flip had stimulated, it would trace the same type of wave line or curve referred to above.

We should note, however, that the rate of vibration would vary with the volume of the gelatin. The more gelatin we had, the slower the vibration would be, that is, the fewer the d.v./sec. we could count; while the less gelatin we had, the greater the number of d.v./sec. we could count.

Air Volume Pitch of the Mouth Cavity. If we disregard heat and altitude, the density of the air is practically constant; so the rate of vibration natural to the volume of air in the vocal cavities is dependent on their size and the diameter of the openings thereto. And these sizes can be varied by the tongue, lips, and other organs.

Vowel Pitch = Whispered Pitch. It is this physical fact which is made use of to explain vowel quality when we talk in terms of the " Cavity

Tone Theories." They refer, so far as the lay reader is concerned, to the whispered vowel.

Cavity Tone Theory Laws. These theories postulate that vowel quality is due to the cavity tone which in its turn is dependent on the size of the cavity and its openings. The smaller the cavity, the greater the number of d.v./sec. its contained air volume will make; the larger the cavity, the slower its mass of contained air will vibrate. Hence the **smaller the cavity the higher the pitch;** and the **larger the cavity the lower the pitch.** A corollary involving the openings must also be taken into consideration, viz., the **larger the opening the higher the pitch;** the **smaller the opening the lower the pitch.**

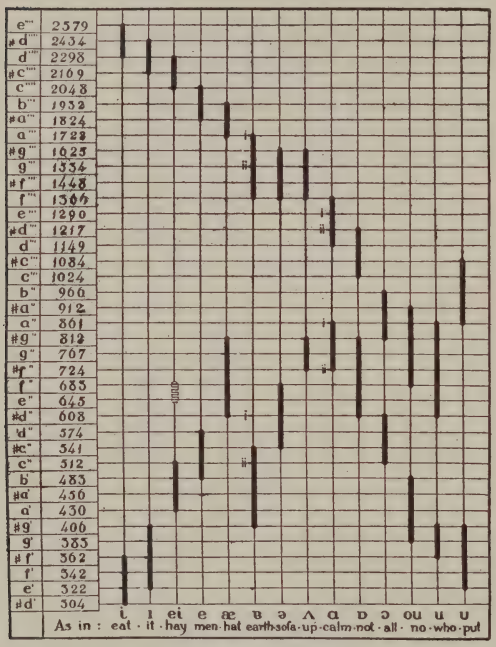


FIG. 5. — SHOWING THE TWO OUTSTANDING CAVITY-TONE PITCH RANGES PAGET THOUGHT HE HEARD FOR EACH VOWEL.

This latter may seem a contradiction to the non-scientific reader since while a large cavity gives a low pitch, a large opening to the cavity gives a high pitch. It is not, however, since the opening governs the pitch in a certain sense, by reason of the freedom with which it permits the vibrations to surge in and out; and hence it can be compared with friction: as the opening gets smaller, the friction increases and slows down the vibration more and more; as the aperture of a cavity gets larger, the surge can take place more rapidly and hence the rate of vibration natural to such a cavity is speeded up.

Effect of Surfaces Heretofore Disregarded. The surfaces which form the walls of the cavity must also inevitably affect the rate of vibration in much the same way. But in general it may be said that those who have utilized the cavity-tone theory in accounting for vowel quality have

been content to speak in terms of the resonator or air-volume effect, and to disregard the walls. The author, as will be noted, has therefore laid particular stress on what possible effect the surfaces may have in changing vowel quality. So each one may find this addition to the customary vowel theories to be so strange that he will have to ask himself whether he agrees or not.

Voice Pitch Not Vowel Pitch. The lay reader of course must not confuse the pitch of the cavity tone with that of the voice. As we have noted above, that of the cavity is created by and is natural to the total volume of air, the size of the cavity apertures, and the type of surfaces which inclose the same. In other words this is the pitch we distinguish when we whisper the vowels; and we note that it gets progressively higher as we run through the series *u*, *o*, *a*, *e*, *i* (oo, oh, ah, eh, ee). Study those in Fig. 5.

Voice Pitch. But the pitch of the voice is created by the vibration of the glottal lips (" vocal cords "); that is the vibration we feel when we place the finger on the " Adam's apple " and say z-z-z-z-z- (compare with the whispered s-s-s-s-s-s- which has no voiced pitch). It is with this voice pitch that we sing when we keep the vowel constant, yet raise and lower the voice at will. This voice pitch also serves our speech in a like manner by varying its shades of meaning. It is what we call intonation. The vocal cord pitch also functions to make our speech sounds audible at a greater distance; and although theories vary in their explanation of this fact, we may at least say that the voice vibration acts then in a way somewhat analogous to that of the radio carrier wave — the waves of the speech patterns are superimposed upon that of the vocal cords, as is shown in Fig. 6; and the small superimposed speech and voice quality vibrations correspond then to what for convenience are herein referred to as " upper partials." [1]

How Voice Pitch Stimulates Vowel Pitch. Of course in ordinary voiced speech, and in song, it is the impulse originating in the vibration of the vocal cords which stimulates the vowel cavity. So the glottal vibration also serves as the cavity tone actuator. And in the whisper we merely substitute an air hiss or rasp for the voice.

In the glottal note as will be explained later we inevitably have present

[1] Our term " partials " is not therefore necessarily synonymous with " harmonics " or " overtones." We apply it to any component or part of a complex sound whether harmonic or inharmonic. We need such a term.

a whole range of partials. That is, there is the octave, and the octave of the octave, the fourth, the fifth, etc. And as these overtones, harmonics, or upper partials get higher and higher in pitch, they normally progressively diminish in loudness. The harmonic vowel theories (both fixed, or steady state, and relative) look upon the function of the cavities as serving to increase the loudness of those overtones in the glottal sound which have the same pitch as that of the cavity. This function of a cavity is what the physicist calls "resonance." This is explained more in detail in the chapter on cavities.

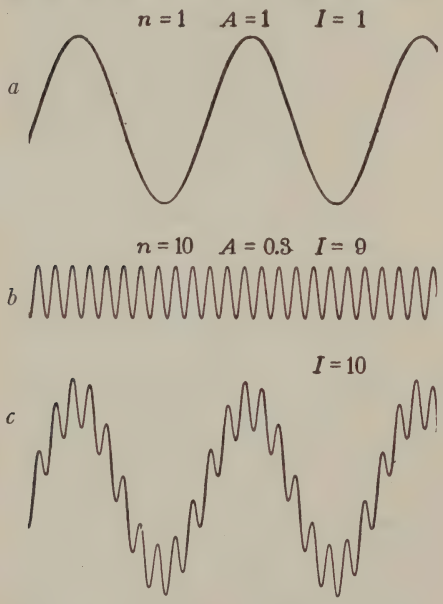


FIG. 6. — IF TWO SOUNDS GIVING *a* AND *b* ARE MERGED *c* RESULTS. NOTE THE COMPARATIVE AND RELATIVE EFFECTS OF THE THREE FACTORS, PARTICULARLY THE RESULTING RESONANCE OR LOUDNESS. *n* = FREQUENCY OR PITCH; *A*, AMPLITUDE; *I*, INTENSITY OR LOUDNESS.

Loudness Not Resonance. The loudness of the voice may also vary, and this is often erroneously spoken of as "resonance" by those who describe a loud voice as "resonant" or "vibrant." It is then said to have carrying power. But the carrying power of a sound varies with its sonority or loudness, rather than its resonance. The latter term is therefore a misnomer and should not be used in that manner.

Loudness Not Air Movement. The lay reader should not draw the false conclusion that the voice is carried to the ends of a large hall, for example, on a stream of air issuing from the mouth. The actual amount of air in the current which passes through the glottis probably exercises

practically no air current influence on the air in the hall at even a distance of a few yards from the mouth. In other words when we sing loudly we do not fling the air current out to the ends of the hall as some might think. It is, we might repeat, the energy waves which we transmit.

Prolonged Voice = Repeated Shock. This voice wave again is unlike the single shock produced by the one pebble we threw into the pond. The waves in speech do not taper off as long as the vowel is being vigorously prolonged, because the vocal cords repeat their shocks at the rate of so many per second. If they open and close 256 times per second they produce 256 such shocks in that time, and a sound results having a pitch of middle C on the piano, which we classify as having a frequency of 256 d.v./sec. This pitch also carries that of the vowel or the characteristics of the vowel quality with it, and this is constantly renewed so long as the shocks of the voice vibration are repeated. Hence neither dies out as the ripples on the pond do where only one shock is given.

Loudness = Amplitude of Oscillation. Neither does the loudness of the speech sound have anything to do with the distance we can force the air current; for its loudness is dependent on the amount of energy behind the shock, or, if you will, on the amplitude (extent) of the swing, or oscillation of the vibration. This oscillation, we can best illustrate, by citing the swing of the pendulum again. The force of the push we give it will determine how far out it will swing each time; and the farther it swings, the farther it will knock anything else that happens to get in its way. In a like manner, loud speaking or loud singing is dependent on the energy behind the attack; and this does not mean that a large amount of air is allowed to escape; it means merely that the muscles expel that air with considerable force, and that the " vocal cords " or rather glottal lips offer such an impediment as to transmit the number of vibrations they emit per second, with a force manifest in an amplitude which increases as the energy which creates the same gets greater (providing the pitch is kept constant).

Definitions: Pitch (Frequency), Loudness (Amplitude). The number of d.v./sec. refers, therefore, to the number of wave crests which pass a fixed point in a second and is an expression of the vibration **frequency** which creates the **pitch** of any sound. The **amplitude** or height of the wave or vibration train, being a resultant of the energy behind it, or of the force which propagated it, is an expression which in lieu of any

other must often stand for the physical statement of its **loudness.** It must be borne in mind, however, that if we take a pitch at say 256 d.v./sec. showing a curve of a given amplitude, that that same amplitude will not represent the same loudness in its octave of 512 d.v./sec.; for the term amplitude is an expression of the physics of the sound, as is the term "intensity," and the term "loudness" is one we apply to what the ear hears.

D. C. Miller makes a very lucid statement of the correspondence between the two, in words which even the non-technical reader can understand if he will pause long enough to weigh them carefully:

If the frequency remains constant,

" The *energy*, or what we will call the intensity of a simple vibratory motion, varies as the square of the amplitude."

If the amplitude remains constant,

" the energy varies as the square of the frequency " (or pitch).

When both frequency and amplitude vary,

" the intensity (or energy) varies as the square of the product of amplitude and frequency."

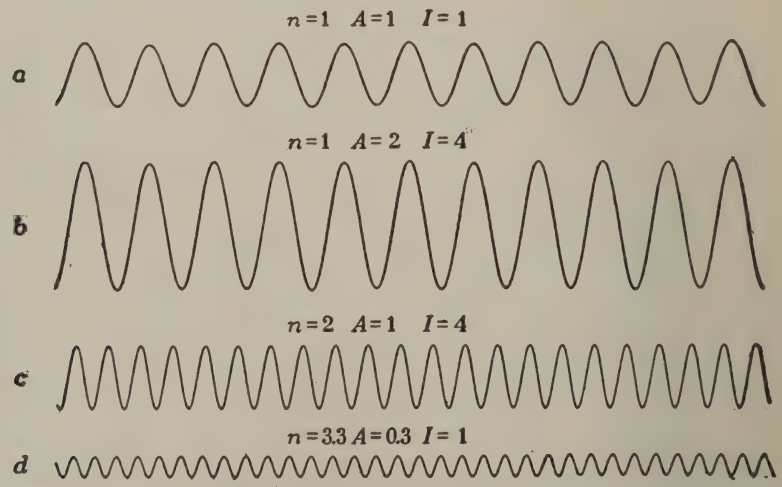


FIG. 7. — TO ILLUSTRATE MILLER'S THREE-PART STATEMENT OF THE PITCH-LOUDNESS LAW WITH CURVE *a* TAKEN AS THE NORM = 1; WHERE n = FREQUENCY OR PITCH; A = AMPLITUDE OR CURVE HEIGHT; I = INTENSITY, ENERGY, OR LOUDNESS.

Hence it will be seen that a given intensity requires a progressively decreasing amplitude as the pitch gets higher. These facts, taken from Miller, are graphically portrayed in Fig. 3. But it must be borne in mind that the term "intensity" used by the physicist, while it is generally synonymous with "loudness," may yet manifest something radically different, if only because the ear favors certain pitches. *Intensity* is a physical term; *loudness* a physiological or psychological one.

Original Loudness Altered by Surfaces. It will be seen that anything which decreases the energy behind a sound, deadens its loudness. The friction which soft surfaces set up does just this — they absorb the energy which propagates the sound. This is what is referred to in the chapter on surfaces and elsewhere herein, when we say a sound, or one of its partials, or groups of partials, is deadened.

Quality (Timbre) = Varying Pitch-Loudness Relationships. All sounds manifest, in addition to these factors of **pitch, loudness** (or **intensity**), and **quantity** (or **duration**), another which we call **timbre** (**quality** or **clang**). This quality which we hear in a sound is primarily a manifestation of the varying relationships which exist between, and the loudness of a group of pitches, normally perceived as a fused whole, much as is a piano chord, when three or four tones are struck simultaneously but are heard more or less as one, with varying minor or major quality.[2] The origin thereof is to be sought, of course, mostly in the overtones present in the vocal cord sound as above explained. We shall consider as we go how a loading of the cords, cavity air volume resonators, and the varying involvement of hard and soft surfaces in the cavities alter what we call quality or timbre. As will be seen this is the factor we are most concerned with in a study of differences in vowel and voice quality. Quality, in other words, is at least in a large measure a manifestation of pitch, and in a vowel that quality distinguishing pitch is best perceived when it is whispered. The "characteristic" vowel pitch should not therefore be confused with the voice or intonation pitch.

[2] Curve *c* of Fig. 6 illustrates this. Both pitches heard in the sounds which produced curves *a* and *b* are heard in *c*. The loudness is heard as the summation of that of the two; but the quality differs from that of either. Since the pitch and loudness relationships both govern quality, the effect of merging the *a* and *c* of Fig. 7 will not be the same, either, as that of combining *b* and *c*, though the pitches are the same; *a* and *c* will give a more "*metallic*," *b* and *c* a more "*mellow*," "*full*," or "*dark*" quality. But *a* and *d* merging their inharmonic pitches will produce a quite different "*strident*" quality.

CHAPTER V

HEARING

"In the Helmholtz theory, as first formulated, it is stated that the organ of Corti located between the basilar membrane and the tectorial membrane acts like a set of resonators which are sharply tuned. Each tone stimulates a single organ depending upon its pitch. Later this theory was somewhat modified as it was thought that the resonant property might reside in one of the membranes in the cochlea.

"In the 'telephone' theory, as expounded by Voltalini, Rutherford Waller and others, it is assumed that the basilar membrane vibrates as a whole like the diaphragm of a telephone receiver and consequently responds to all frequencies with varying degrees of amplitude.

"Meyers* in his theory states that various lengths of basilar membrane are set in motion depending upon the intensity of the stimulating tone. As in the previous theory, the pitch discrimination is accomplished in some way in the brain.

"In the 'non-resonant' theory of Emile ter Kuile it is assumed that the sound disturbance penetrates different distances into the cochlea depending upon the frequency of the stimulating tone. The further along the membrane the disturbance reaches, the lower will be the pitch sensation. A low pitch tone then stimulates all of the nerve fibres that would be stimulated by tones of higher pitch plus some additional nerve fibres.

"The theory of maximum amplitudes was first put into definite form by Gray in 1899. (See Gray, *Jour. Anat. Phys.* **34**, p. 324, 1900.) It assumes that the position of maximum amplitude of the basilar membrane varies with the pitch of the stimulating tone. Although a considerable portion of the membrane vibrates when stimulated by a pure tone, the ear judges the pitch by the position of maximum response of the basilar membrane. Roaf has shown that some action of this sort must take place due to the dynamical constants involved. (See Roaf, *Phil. Mag.* **43**, pp. 349–354, Feb., 1922.) It is an amplification of this theory that I propose as the one which most satisfactorily accounts for the facts. . . .

"The entire membrane vibrates for every incident tone, but for each frequency

* Meyer himself protests this summary and says his "hydraulic cochlea model which contains a totally unstretched, even flabby, phragma made of softest leather, in a viscous fluid, illustrates his theory. It shows that when there is an hydraulic pressure difference between the two windows, a bulge forms and lengthens (not 'travels') toward the apex in proportion to the 'amplitude' of the pressure difference. As soon as the pressure difference changes 'sign,' a bulge forms on the other side of the phragma and lengthens toward the apex, to its extent annihilating the previous bulge step by step. Mathematically this is a 'discontinuous' function, a rare example in physics. Obviously the rapidity of the 'sign' change corresponds to the pitch."

"If the external oscillation is 'compound,' the result then is a marking off of (part of) the phragma into lengths, of which each has its own frequency of being shaken. The perceptive analysis is thus made within the cochlea." Meyer emphatically denies that the sound analysis is postponed (as suggested by Bonnier and many others) until the brain is reached. The cochlea is the analyser.

The intensity of each pitch depends on the number of sensitive cells stimulated in the cochlea; or, what is virtually the same statement, on the "length" of the phragma division.

there is a corresponding spot on the membrane where the amplitude of the vibration is greater than anywhere else. Our postulate is that only those nerves are stimulated which are at the particular parts of the membrane vibrating with more than a certain critical amplitude; and that we judge the pitch from the part of the membrane where the nerves are stimulated." — Dr. Harvey Fletcher (1923).[1]

Our Interest in Hearing Function as It Bears on Vowel and Voice Quality Theories. We have limited ourselves herein to a consideration of the manner in which differences in quality of speech and voice are produced, and so are absolved from any necessity of treating the physiological processes involved in the ear, nerve channel, and brain interpretation thereof. Yet it would seem wise to include the basic facts.

What Is Hearing? It will suffice to say that scientific thought generally concedes that this combined function of ear mechanism, nerves, and brain unites to catch, break up into varied component parts, transmit, and combine for final interpretation those oscillations in the air which so stimulate the whole as to be interpreted as **sound.** Such we believe to be the manifestation known as **hearing.** We no longer conceive of hearing as being one gross process. Helmholtz has the credit for making us see that this sensation which we know as hearing may well consist of a highly specialized breaking-up and fusing process; all of which makes possible the finest distinction perceptions. This known fact results in the auditory sensation being classified as one of the most, if not the most discriminatory of the five senses; and is undoubtedly one of the principal reasons why it is so much more sensitive than most of them.

The Helmholtz Theory. Of course it is doubtful whether anybody would accept at the present time the theories supported by Helmholtz just as he advanced them.[2] For example, there may be doubt whether any single fiber or cell on the basilar membrane can reasonably have a frequency which will respond to the very low or even to a differentiation between the very high pitches heard regularly in sounds; or whether the one can be stimulated without stimulating the other.

He conceived of that stimulus, it will be remembered, as being a movement in the liquid of the *cochlea* (or long canal wound round itself in a snail-shell-like formation). This would of course inevitably be set to oscillating when the sound waves struck the ear drum (*membrana tympani*) and were transmitted thereto by way of the bones of the middle ear

[1] Fletcher, Harvey. "Physical Measurements of Audition and Their Bearing on the Theory of Hearing," *Jour. Franklin Institute*, Sept., 1923, pp. 289, 310–312.

[2] Helmholtz. *Lehre d. Tonempfindungen*, 5 Aufl. p. 235, 1896.

(*malleus, incus, stapes*) through the *fenestra ovalis*. This liquid is in contact throughout its length with the spiral interior wall which forms the separation medium on the interior of the *cochlea* which starts as a bony division at the center but ends along its outer edge in a membrane extension (*membrana basilaris*) which follows round all the way up to the tip. Fibers of this latter carry sets of supporting cells of varying sizes and certain fine hair cells. These were presumed to have different periods of free vibration which were readily set into periodic motion at the slightest oscillation in the liquid. They would ostensibly respond, therefore, in much the same manner as do strings on two pianos when the key on one is struck and the string of the other across the room, stimulated by reason of sympathetic vibration, responds to its own pitch, or in a lesser degree to one of its harmonics.

It has been objected that every one of the fibers along the membrane would have to vibrate since they are all fixed to and influenced by the same medium; and Wegel [3] has demonstrated how under such physical circumstances the one which corresponds to a given frequency inevitably responds most violently, but that those which fall on either side of it do likewise to a progressively less extent. The harmonics react in a like manner.

It was suggested [4] that since the fibers of the membrane have small hairs at the end of the cells these would rub against a floating membrane when set into vibration; and that this would result in a stimulation to the nerve endings around them, which would be transmitted to the brain by means of the nerve fibers. The observation that there were more of these fibers, cells, and nerves than were thought to be needed for the tones which we can perceive was held to lend color to this viewpoint.[5]

Anatomists now generally agree, however, that there are only around some 4000 nerve cells in the basilar membrane with four or five fiber hairs for each cell. Yet there are some 300,000 tone units in the auditory-sensation area. Until quite recently it was conceded that nerve impulses never travel much more rapidly than at a rate of around 50 per second, whereas as we know normal hearing is able to perceive tones oscillating at the rate of from 16,000 to 20,000 some odd cycles per second. It has also been discovered that all of these nerve fibers do not end

[3] Wegel, R. L. Theory of Telephone Receivers, *J. A. I. E. E.*, XL (1921).

[4] ter Kuile. "D. Uebertr. d. Energie v. d. Grundmembran a. d. Haarzellen," *Arch. f. d. ges. Physiol.* (Pflüger), LXXIX (1900), p. 146.

[5] Snodgrass and M'Kendrick. See Schaefer's *Textbook of Physiology*, II, 1184. Edinburgh, 1900.

in individual cells along the basilar membrane. This fact, coupled with the ones above mentioned and quite a number of others, taken separately or all combined, have created renewed and undisputed doubt as to exactly what the physiological processes involved in " hearing " are.

Recent Apparatus Brought Changed Theories. The vacuum tube, the thermal receiver, the condenser, and the transmitter have made it possible to test, with much greater accuracy and under adequately controlled conditions, first a wide range of pitches with definite knowledge that the pure tone, and not an upper or subharmonic thereof is being tested. This was an accomplishment impossible for Helmholtz, and for scientists generally until very recent times. They have made it possible, second, to test each pitch in accordance with a progressively variable and definitely established scale of loudness, just as we gauge temperature by means of a thermometer.[6]

Significance of These New Facts. We know now as a result of recent work with such apparatus that even the individual we consider possessed of " normal hearing " often manifests pitch bands where his acuity shows a varying degree of slump or dip, and that these bands or " islands of tone deafness " vary from individual to individual. But isolated pitch involvement postulated by the Helmholtz theory is not characteristic even in impaired hearing. These findings show further that as deafness begins to creep on, particularly with old age, the acuity of hearing diminishes not equally over the whole range of pitches, but in a varying degree for different pitch ranges, the loss in the specific case mentioned taking place as a rule in the high pitch band first. We know too that the deaf person who is actually incapable of hearing sound at any degree of loudness whatever on all pitches, and that, for both ears, is comparatively rare. For the most part, his deafness is only relative. So long as the ear structure has not been destroyed as in *traumatic*, or in certain *pathological* or *surgically impaired* cases, and the few others of evidently the same type, sound may be amplified for the individual so that he can hear pitches within his range. But the band of frequencies on which each can hear best varies from individual to individual, and the degree of acuity for different pitches, or in other words loudness loss, likewise

[6] Fletcher, H. "The Nature of Speech and Its Interpretation," *Jour. Franklin Inst.*, CXCIII (1922), p. 729.
Ibid. "Methods and Apparatus for Testing Hearing," *The Laryngoscope*, XXXV, No. 7, July, 1925.

varies. Each case and even each ear presents a different pattern of perceivable loudness and pitch ranges.[7]

Summary. The facts as we now know them seem to prove definitely: First, that the hearing mechanism does not function as a whole. It does not always perceive one gross sensation or sound pattern, since we know that some " ears " are incapable of, and others later develop a loss of power to perceive certain elements forming a part of that pattern. This does not necessarily involve an impairment of the ability to receive and interpret the other pitch elements as they are manifest in varying loudness and duration.

Second, that hearing is without question a function in which the various pitches which we know to be necessary in the constitution of differences in *timbre* or quality are separately perceived, though interpreted as a whole. For as stated above, the evidence clearly indicates that an ear may lose the power to catch certain bands of pitches at given degrees of loudness, and that without impairment of ability to perceive the others.

Third, that the three factors involved in distinctions in the quality of speech, namely, pitch, loudness, and duration or quantity, may all be individually differentiated in the hearing mechanism, even though they are finally interpreted as one sound having some given quality.

Then too we may add to this summary the conclusion that, at least so far as the author can see, the evidence also clearly indicates that our hearing has the power of separately perceiving and fusing as a part of the interpretation inharmonic elements, as well as harmonic elements, in the quality components of a sound.

Bearing on Vowel Theories. Proponents of the Helmholtz theory of audition have not always been willing to admit this latter conclusion. Many of them have been prone to utilize his audition theory either as evidence in favor of what has been erroneously called his resonance or harmonic vowel theory (though as we have shown this should be credited to Wheatstone) or have coupled the two theories and insisted that any facts tending to overthrow the cavity-tone resonance vowel theory could not be accepted, since to do so would leave us without any adequate theory of audition.

[7] E. R. Abernathy, principal at the Ohio State School for the Deaf, a student and colleague of the author's, is now conducting a very interesting investigation into the patterns manifest in families.

Enough has been quoted from Fletcher, as a preliminary to this chapter, to show that this assumption is not justified. As a matter of fact, it will be seen that the general tendency for years past rather has been to lean farther and farther away from any such implication — if it is contained in the Helmholtz theory of audition.

Relation of X-Ray Evidence. So far as the X-ray and laryngoperiskopik evidence presented herein is concerned it would seem to indicate a necessity for taking cognizance of inharmonic elements — at least in differences of voice quality and in the other variations of quality which distinguish numerous speech sounds. Such are undoubtedly present therein, and any theory of hearing to be adequate must take cognizance of these.

But in dealing with this question of hearing, in spite of the extreme delicacy of the mechanism involved, and its inaccessibility for purposes of direct examination, we are not limited entirely to theory.

Some Facts. Fletcher's summary of the principal facts which are generally known is as follows:

"1. Pure tones are sensed by the ear and differentiated by means of the properties *pitch* and *loudness*.

"2. When two notes, separated by a musical interval, are sounded together, they are sensed as two separate notes. They would never be taken for a tone having the intermediate pitch. In this respect, hearing is radically different from seeing. When a red and a green light are mixed together, the impression received by the eye is that of yellow, an intermediate color between the two.

"3. There is a definite limiting difference in pitch that can just be sensed.

"4. There is a definite limiting difference in intensity that can just be sensed.

"5. There is a minimum intensity of sound below which there is no sensation.

"6. There is an upper limit on the pitch scale above which no auditory sensation is produced.

"7. There is a lower limit on the pitch scale below which there is no auditory sensation produced.

"8. The ear perceives tones separated by an octave as being very similar sensations.

"Another quality of audition which is not so commonly known was pointed out by A. M. Mayer. He stated that high tones can be completely masked by louder lower tones while intense higher tones cannot obliterate lower ones though the latter are very weak. Experiments . . . show that this state-

ment must be modified somewhat. Very intense low ones will produce a masking effect upon still lower tones, although the masking effect is very much more pronounced in the opposite case. Many of the opponents of the Helmholtz resonant theory of hearing claim that this fact is fatal to such a theory."

Pitch Limits in Audibility. There are of course many other known facts which, however, are of less importance to us here. Though to the above we may add that through the work of Dr. Vern O. Knudsen of the University of California at Los Angeles, we now know what the sensibility of the normal ear is for small differences of not only pitch but intensity. And it is clear that the Helmholtz figures, still so often quoted, must be radically modified. While the upper limit of pitch audibility may run in many ears around 20,000 d.v./sec. the modern tendency will be to use as the upper limit for all practical purposes not more than 16,000 to 18,000, rather than the 40,000 odd which Helmholtz was inclined to insist upon. There is perhaps no occasion to change the lower limit (though in speech work 64 d.v./sec. may be considered to be the lowest pitch ordinarily used and even that in but an intonation growl), for 80 d.v./sec. would probably be the more normal limit. For our purposes this limit is less important, and it is of course evident that it has nothing to do with the actual lower limit of hearing audibility. On the other hand, the definite fixation of the actual upper limit may finally prove to be of vital importance, since the upper frequencies may ultimately turn out to be those which condition certain differences in voice quality and even those differences manifest as between vowels. However, at the present time we usually content ourselves in most of our speech analyses with a consideration of frequencies running but slightly above 8000 d.v./sec. as the upper limit worthy of consideration.

Loudness in Audibility. The actual facts known in regard to perception of variation in loudness are not so readily fixed — for their effective study is of more recent date, and there are more baffling problems involved. The present study is not so much interested in this aspect of hearing, since it is not immediately involved in the problem of what causes speech and voice quality differences. Nevertheless it might be well to note one or two of the most outstanding recently uncovered facts.

Fletcher notes [8] three generalizations of distinct interest.

[8] *Op. cit.*, pp. 302, 299, 309, 318.

"The loudness of complex sounds usually increases faster with increases in intensity than that of pure tones. This would be expected since the threshold is determined principally by the loudest frequency in the complex sound, and as the intensity is increased, the other frequencies begin to add to the total loudness.

"If two complex tones are judged equally loud at one intensity level and then each is magnified equal amounts in intensity, they then may or may not sound equally loud.

"The sensation produced by a complex sound is different in character as well as in intensity when the sound is increased or decreased in intensity without distortion. In general, as the tone becomes more intense the low tones become more prominent because the high tones are masked."

He has also arranged a **loudness scale** which has now received such wide acceptance as practically to supplant any other measurement heretofore used. It is that used in the Western Electric Audiometer. In his words, this

"loudness scale has been chosen such that the loudness change is equal to ten times the common logarithm of the intensity ratio. A pitch scale has been chosen such that the pitch change is equal to 100 times the logarithm to the base two of the frequency ratio. The loudness of complex or simple tones is measured in terms of the number of loudness units a tone of 700 cycles must be raised above its average threshold value before it sounds equally loud to the sound measured. This frequency was arbitrarily chosen as a standard for measuring loudness because its loudness value corresponding to the threshold pressure for normal ears is exactly 0.001 dyne, and because it is close to the frequency at which the loudest tones used in conversational speech occur."

Such, as we now know them, are the most essential facts pertaining to the hearing process. At least these are the modern developments which appear to the author as the ones most likely to be of interest to the reader of this study. Their bearing on theories used to account for differences in the quality of speech and voice may of course be very vital. Yet it will be seen that we are in quite as much of a state of disagreement about the hearing process as we are about the physiological processes involved in production.

CHAPTER VI

CAVITIES

"We have discussed cases of resonance generated in such air chambers as were capable of reinforcing the prime tone principally, but also a certain number of the harmonic upper partials. . . . The case may occur in which the lowest tone of the resonance chamber . . . corresponds only with some of the upper partials." . . . (Then) "the corresponding upper partial is really more reinforced than the prime or other partials by the resonance of the chamber, and consequently predominates extremely over all the other partials in the series. . . . The vowels of speech are in reality tones produced by membranous tongues (the vocal cords), with a resonance chamber (the mouth) capable of altering in length, width, and pitch of resonance, and hence capable also of reinforcing at different times different partials of the compound tone to which it is applied."

— WHEATSTONE[1] THEORY SUMMARIZED BY HELMHOLTZ.

ARE CAVITY TONES THE SOLE CAUSE OF QUALITY?

The Same Cavities Sometimes Produce Different Vowel Qualities. There is no question but that exactly the same combination of cavities which give *e*, for example, can also be forced to produce *i* or *ɪ*. This fact is somewhat disturbing to all theories held at present in regard to the cause of differences in vowel quality. But it has been amply proved. The author called attention to this particular case in a demonstration of artificial vowels which Sir Richard Paget[2] was kind enough to give recently before Professors Boas, Gottheil, Gray, Krapp, Pupin, Weeks, and quite a number of others. Paget's vowel ɛ was produced with a cardboard cylindrical resonator, divided into two parts which have natural periods of 1722 and 406 d.v./sec. It was constructed to speak ɛ as in *men* when stimulated by a variable pitched organ-pipe reed to which it may be attached — that is, when the reed is kept low-pitched, being, let us say, between 80 and 100 d.v./sec. But when the pitch of this reed was raised another vowel resulted without the cavities having been

[1] See Chap. II herein, and Wheatstone, *London and Westminster Review*, 1837, p. 27.
[2] See Paget, "The Production of Artificial Vowel Sounds," *Proc. Roy. Soc. A.*, CII, 1923. (Same.) Letter of Mar. 3, 1922. *Nature*, CIX, No. 2733, p. 341. *Ibid.* *Vowel Resonances*, Int. Phon. Assn., 1922.

changed in the slightest. This latter vowel was then variously heard as *i* or *ɪ*.

Vowel Change Due to Glottal Pitch Change. Here, then, is a phenomenon which needs to be taken into consideration when we seek any explanation of differences in vowel quality. Our observation, if valid throughout, would be tantamount to saying that we may change the vowel quality by varying the glottal tone. This is directly contrary to what Willis has said;[3] and practically all scientists have followed his concept since that time, either by open admission or by implication.[4]

Results for Other Vowels. A test of the other vowels for which Sir Richard had resonators at that time gave similarly interesting results. They were five in number. A table showing complete results of the test as registered by nine observers is given below. It will be noted that there was no complete agreement in any one case as to the vowel produced. This is partly due to the fact that both a high and low pitch were given. However, only one trial was produced on the former and several on the latter, which would make it stand out in the consciousness of the observer who was trying hard to guess at what was being produced.[5] Without this variation in glottal tone it may be taken for granted that the vowels on a low-pitched reed tone were what they were supposed to be, as shown in the following pairs, on the upper line. When the pitch of the reed (corresponding to the glottal tone) was raised, the vowel quality was heard as changed to that given in the lower line of the pairs, as follows:

TABLE NO. 1

Glottal Tone	Vowel Heard				
Normal low pitched: . . .	*ɪ*	*ɛ*	*a*	*ɔ:*	*u*
Reed high pitched: . . .	*i*	*I* or *i*	ə or *æ*	ə or *a*	ə or *Y*
Resonator frequencies . .	2169	1722	1084	861	812
	271	406	683	483	322

[3] Willis. "On Vowel Sounds and on Reed-Organ Pipes," *Trans. Camb. Phil. Soc.*, III (1830), p. 231.

[4] Miller. *Science of Musical Sounds*, 2nd ed., Macmillan, 1922, pp. 217 and 230, etc.

[5] No intimation was given the observers ahead of time as to what vowel it was proposed to reproduce in each case.

TABLE NO. 2

Artificial Vowels

Results of a test made at Columbia University, New York, March, 1927, in Room 402, Philosophy Hall (dimensions about 10 × 15 ft.; ceiling 9 ft.). Nine observers, including five with but a modicum of phonetic training which might carry with it consequent preconceived theories.

The tabulation below shows their attempts to detect what vowel Sir Richard Paget was trying to reproduce by means of his cardboard resonators actuated by an organ-pipe reed of variable pitch, operated from a foot bellows. The reed was inserted in a conventional lead tube some eight inches long which in turn was placed in a brass tube several feet long connected to the bellows by a rubber tube of sufficient length to allow ease of manipulation. Both of these tubes were some one-half to three-fourths of an inch in diameter.

All vowels were given in combination with first one consonant, then another, thus:

pa-pa-pa-pa-pa
ma-ma-ma-ma-ma
fa-fa-fa-fa-fa

made by opening and closing the mouth of the resonator with the palm of the hand. Each of these operations was repeated a number of times. For each vowel the pitch of the reed was raised for one more trial before passing to the next. No comment was made which might indicate what vowel was being produced, except in the case of the vowel *i* when Sir Richard alternated it with the vowel ɛ saying: "Now compare that one with this."

Where any observer vacillated between two sounds, and called attention to his doubt, both are cited below. The resonance frequencies for each of Sir Richard's vowels are given above in Table 1. Compare these with those he shows in Fig. 5.

Alphabet Used for Recording (and Accompanying Examples) as Placed on the Board before Starting, to Be Used by All as a Guide	Used Resonators Intended to Reproduce				
	a 1st vowel tried	ɔ: 2nd tried	ɛ 3rd tried	*I* 4th tried	*u* 5th tried
		Tabulation	of what ob	servers hear	d
ə *the, idea*	1	1			1
i pea	1		3	7	
I pin			2	3	1
e pace		1	5		
ɛ *pet*		1	1		
æ *pat*	1				
a ah	5	5			
ɔ *bawl*	1	4			
o bone					1
u fool	1				9

Analysis of X-Rays

A Pitch and Tonal Color Change — Same Vowel. One case of pitch change in the X-rays herein, for which there is a radical variation in cavity for the same vowel by the same individual, is shown in Figs. 83, 84, 85, and 86. Here the auditory effect is to change the tonal or so-called " voice-placement " quality, rather than the vowel quality. So while the vowel remains the same, the cavities are altered. But if there is any factor responsible for the change in the cavity, it is probably this seeking for " placement color," rather than the influence of the change in pitch.

Cavities Lack Uniformity — Same Vowel. Yet it cannot be denied that throughout our series of X-rays there is manifest a striking lack of uniformity in cavities. It apparently cannot be said that all individuals take the same position for a given cavity in order to produce a given vowel. Yet there are some characteristics which are fairly outstanding.

Vowel Ah (*a*). We have noted that in order to produce an *a* (ah) there apparently must be a constriction between the epiglottis and the pharyngeal walls. See Figs. 111, 123, 124, 136, 149, 75, 66, 83, 86. This seems to be true even for the " pinched " or " tight " singing tone reproduced in Fig. 83. It is also to be noted that all the vowels in the series from there up to *i* (ee) tend to narrow the palatal cavity, and widen that of the pharyngeal. See Figs. 96, 97, 101, 102, 106–110, 117–122, 131–135, 143–147, 150, 151, 154, etc. Compare with 149, 155, etc.

Other Vowels — Back. It is harder to make a generalization in regard to the back vowels, since the openings (especially the lips) seem to be more radically involved. But it would seem to be justifiable to say that in general the upper back cavity has a tendency to narrow and " pinch in " the escaping glottal tone between soft surfaces, and the lower pharynx to get progressively larger from ɔ (aw) to *u* (oo).

Openings. This leads us to a consideration of the effect of such openings on these cavities. There are herein manifest not only those between the lips, and the tongue-velum, which we had expected for *u* (oo) as in Fig. 100; but there are also at times for other vowels one between the tongue-pharynx, which we had not been trained to look for, as in Fig. 99; another unexpected one, between the epiglottis and pharynx, as in Fig. 104; another we have not been accustomed to call attention to,

between the cushion of the epiglottis (or tip of the epiglottis) and the posterior edge of the larynx, as in Fig. 110; and even one between the tip of the tongue and palate or teeth, as in Fig. 105. All of these are in addition to the opening we sometimes think of as causing nasality — but which does not necessarily do so. It, by the way, may change the pitch of the cavities below, viz., that between the velum and pharynx.

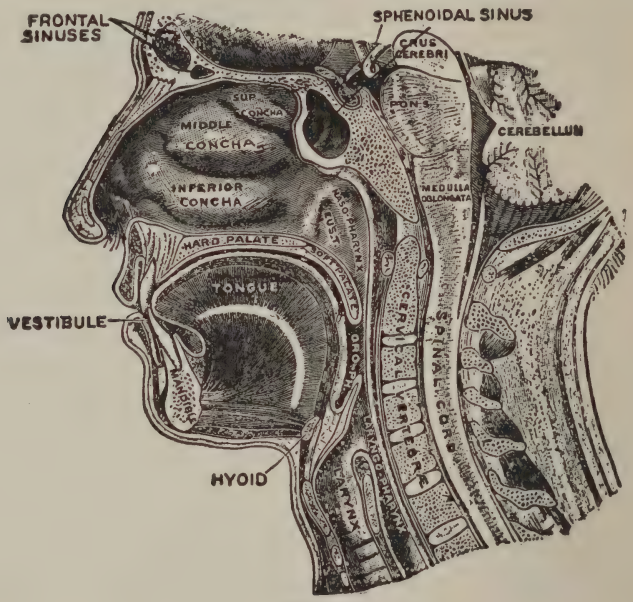


FIG. 8

Physiological Study Necessary. It seems to the author entirely unscientific for one to jump at the conclusion that this whole question of vocal cavities and their openings is too complex for us to consider. There surely must be a means of ascertaining the effect these factors which such a complicated cavity or series of cavities might in general be expected to produce may have on the tone. It may be necessary to construct artificial cavities in order to test them — an interesting task for somebody to undertake. We have some initial information in the experiments of Paget.[6] In the construction of his artificial vowel resonators he found, for example, that adding one cavity to another lowers the natural period of both cavities :[7]

[6] Paget. "The Production of Artificial Vowel Sounds," *Proc. Royal Soc. A*, CII (1923), pp. 752–765.
[7] *Ibid.*, pp. 762–763.

"The effect of joining two resonators, the one with larynx attached at one end and the other end open, and the other with both orifices open, is in general to lower the resonance of each, but in different proportions according to their relative capacities, and to the relative areas of the common central orifice and the front orifice of the front resonator."

Coupling Two or More Cavities. If by joining two cavities together you lower the pitch of each of them, does it follow that when you add a third cavity you will lower the pitch of all three? What will be the effect if you *cut* the third cavity in over the juncture of the other two? Will the effect be any different if you cut in over the end of but one of the two right at the point where it turns to join the other at right angles, as in Fig. 104? An answer to such questions has a definite bearing on the validity of our present vowel theories. If this opening of the nasal passage, as in Figs. 104, 112, 117, 133, and 134, etc., serves to lower the pitch of both the pharyngeal and palatal cavities, the function of the velum in the production of non-nasal vowels is of considerably more importance than has hitherto been conceded. In that event such experiments as those obtained by the apparatus designed by Prof. Weeks [8] assume added importance and point to the necessity for a more thorough examination of the function of the velum. Scripture [9] and possibly others have indicated that such an opening for a nasal vowel would probably change the mouth tones:

"The relaxation of velar closure across the pharynx allows the upper pharyngeal and the nasal cavities to influence the sound. This gives the sound an auditory characteristic called — not quite accurately — 'nasalization.' [10] This characteristic consists in changes in the cavity tones of the speech sounds. For a given position of the vocal organs the opening of the upper pharyngeal cavity will add tones due to the size of the cavity and the nature of the apertures; it will also necessarily modify some of the tones of the mouth on account of the additional aperture and the reciprocal action of connected cavities. Thus *a* will differ from a^n formed by the same positions of the tongue, lips, etc., not only in having additional cavity tones, but also in changing the mouth tones. To retain the mouth tones unchanged to the ear, the tongue, lips, etc., must make readjustments; this is perhaps the explanation of the fact that for the sound heard as o^n Rousselot finds the tongue position varying from o_1 to o_3."

[8] Weeks, Raymond. "Studies and Notes in Philology and Literature," II (Harvard, 1893), p. 213.
[9] Scripture, E. W. "The Elements of Experimental Phonetics," Scribners, 1902, p. 346.
[10] See, Sanger, "Ueber d. Entstehung d. Näselns," *Pflüger's Arch. f. d. ges. Physiol.*, LXVI (1897), p. 467.

Velar Opening without Nasality. Herein we refer, however, not to a nasal tone, or to any quality of nasalization. In order to produce this effect, it is apparently necessary to do something else besides just open the passage into the nose. When we listen to the phonograph records made at the time the X-rays 119 and 121 were being exposed, we fail to notice that there is manifest any difference in the vowel quality of either, and no " nasalization " quality in 121. This should be self-evident, in any event. It is peculiar that the contrary idea should continue to be repeated. We meet and associate with scores of men every day who use what voice teachers would designate as the resonance of the nasal cavities, and yet there is not a trace of " nasality " in their vowels. Because of this fact, such teachers have come to distinguish between " nasality " and " nasal resonance."

In order to produce the so-called nasal quality, it is necessary to close one of the cavities at the end, so as to pen the sound in a sort of *cul de sac*. It is the palatal cavity which is thus involved in the production of an *m* or *n*. If an individual who habitually uses nasal resonance gets a " cold " and the nasal turbinates become congested enough to close the nose, then the sound which enters the nose is prevented from escaping at the nostrils. The result produced is easily recognizable. An excessive constriction produced by the epiglottis, by the interior larynx, or between the tongue and the walls of the pharynx, may cause the lower pharyngeal cavities to form such a *cul de sac*. There is then given off a tonal quality which the ear recognizes as being somewhat analogous to that produced by swollen turbinates.

Artificially Produced Nasality. Sir Richard Paget does something like this artificially when he lays his hand horizontally against the throat above the hyoid bone, and presses forcibly and suddenly up and back. He thinks that in this fact he has discovered the cause of a well-known type of so-called " nasal twang." Perhaps some such constriction may partially account for part of the quality characteristic of the French nasal vowels. It is well known that many vehemently maintain, especially Frenchmen, that these vowels are not nasal at all.

Use of Nasal Opening Varies. So far as these X-ray experiments are concerned, it may be said that it is not unusual to find subjects who open the nasal passage for some vowels and not for others. This will be observed in the case of subject #291 for example. Figs. 112 for ɔ (aw),

113 for ə (uh), and 115 for *o* (oh) show openings between the velum and pharyngeal wall; whereas Figs. 116 for *u* (oo), 114 for *ʊ* (foot), 111 for *a* (ah), and 110–112 for the vowels *æ* (fat) to *i* (feet), all show the nasal passage entirely closed. These are for a lady's voice. Subject #358, a man, shows the passage open for all vowels. The same may be said for subject #347 (another man), yet the nasal opening is indicated as several times as large in Fig. 96 for subject #347 as it is in Fig. 101 for the other subject. What effect might this variation in the size of the aperture at this point have? How will it change the pitch of the buccal, pharyngeal, and nasal cavities?

Effect of Shunting in Extra Cavity. On page 763 of the previously cited work [11] Paget gives some information which may throw a little light on these questions:

"When a *large front* resonator giving **645**" (d.v./sec.) "with front orifice *24 mm.* diameter and back orifice about *22 mm.* was joined to a *small back* resonator having **812**" (d.v./sec.) "the front resonator *dropped* **10** *semitones*, while the *back* resonator was practically **unchanged.**

"When a *small front* resonator, **2298**" (d.v./sec.) "with *large front orifice, 20 mm.* was joined to a *large back* resonator, **512**" (d.v./sec.) "with *small orifice 8 mm.*, the *front* resonator **fell two** *semitones*, while the *back* resonator **fell five.**"

Cavity Coupling Laws.

"*i.e.* for a front resonator, the maximum fall occurs when the front resonator is large and the back resonator small, and the central orifice is large compared with the front orifice.

"The minimum fall occurs when the front resonator is small compared with the back resonator, and the front orifice is large compared with the central orifice.

"For a back resonator the maximum fall is produced by a large back resonator and small front resonator, with a large central orifice and small front orifice.

"The minimum fall is produced by a small back resonator combined with a large front resonator. In this case the size of the central and front orifices respectively is practically immaterial."

Here we are given some of the basic information necessary to the proper interpretation of the X-ray experiments shown herein. There is of course merely an intimation as to the facts needed. We lack definite

[11] Paget. "Artificial Vowel Sounds," *Proc. Royal Soc. A.* CII (1923), p. 763. Material in parentheses mine, as are the italics and blackface print.

laws which might be established upon the basis of a sufficient number of concrete cases. This is a field for an extensive study which the author hopes may be undertaken by somebody in the near future.

X-Rays Herein Are Prepared for Such Study. In the meantime he has attempted so to present the experiments contained herein as to make their analysis possible in the light of such laws as can be surmised at this stage. Each subject has been so placed in his relationship to the X-ray target and cassette as to make for an amplification which would be constant, and this amplification constant has been kept at exactly 1/10 for the mid-dorsal line in the sagittal section. A marker was generally used to delineate this point so that there might be no mistake. This was especially necessary in the case of the tongue, where this center line very often does not conform to that of the edges. These edge lines, where visible, are shown by dashes or a broken delineation. The solid lines, therefore, will show the mid-dorsal position, and the broken lines the outside.

Value of the Marker. An examination of Figs. 48–61 and numerous others will show that the use of this marker aids us to avoid drawing false conclusions as to the cavity and aperture dimensions which we are to consider in this connection. The marker may often be seen in these photographs where it passes over and delineates the center line on the lower lip — the one most subject to variation. It shows as a black line, except in those cases where the gelatinous gold-foil marker was used. In some cases it is made by the impregnated silk thread process, but this varies as indicated in the chapter on technique. It may also often be seen where it pulls away from the capillary attraction of the tongue to pass down the œsophagus. No effort was made to force the adherence from there on. It was no longer needed to distinguish the edges from the center, after they had passed below the impediment presented by the broad hard surfaces of the jaw bone. (See Figs. 48, 49.) The swallowing process serves to hold the marker to the exact center, and hold it taut enough to keep it from zigzagging. X-ray pictures with such zigzag lines are worthless.

Consideration of Error in Line Tracings. It has been extremely difficult to trace steady lines over the marker on the film and there probably are some slips. But the lines are accurate to within a fraction of a millimeter. This variation at any small point along such an extent of

surface is of negligible importance. In this sense the lines shown in these experiments are far more accurate than any palatograms which have thus far been published, or of any linguagrams or plastographic tracings.

Studies Follow. In the analyses of the X-ray photographs given by groups of vowels, in the chapters which follow, we shall try to apply to these cavities and apertures the facts which have been here indicated in regard to their function. Innumerable studies could be made on the basis of these experiments as they stand. By keeping the amplification and the reduction constant, it is hoped that they have been presented in such a way as to serve those who follow, and may desire to apply the facts uncovered in the necessary investigations which have been partially indicated above.

More Facts Necessary for Accurate Cavity Studies. For this purpose, more information must be had as to the natural periods of coupled cavity systems, and the effects of shunting them in and out. More should also be known as to the effect of variation in the sizes of the openings at their egress and ingress, and these measurements should be indicated in terms of millimeters. More information must be had as to the effect of hard and soft surfaces: first, in altering the natural periods of the cavities; second, in damping the compound tone as a whole, and any effect this may have in changing vowel quality; third, in damping the higher partials and the effect that this may have on the ear in producing what is heard as a " bright " or " metallic " quality in the vowel, in contradistinction to a " mellow " or " dull " or " dead " quality. When we once have such information, we may begin an intelligent consideration of the real cause of differences in vowel quality. So far as the experiments of the present study are concerned, there is no proof that the cavities alone are responsible for all vowel differences.

CHAPTER VII

OUR NEW SURFACE EFFECT THEORY

"Moreover vowels admit of other kinds of alterations in their qualities of tone. . . .

"Flaccid soft walls in any passage with sonorous masses of air, are generally prejudicial to the force of the vibrations. Partly too much of the motion is given off to the outside through the soft masses, partly too much is destroyed by friction within them. *Wooden* organ pipes have a less energetic quality of tone than *metal* ones, and those of *pasteboard* a still *duller* quality. . . .

"The walls of the human throat, and the cheeks, are, however, much more yielding than pasteboard. Hence *if the tone of the voice with all its partials is to* meet with a powerful resonance and *come out unweakened*, these most *flaccid parts* of the passage for our voice *must be* as much as possible *thrown out of action*, or else rendered elastic by tension, and in addition the *passage must be* made as *short* and *wide* as possible. . . .

"The lips, when their cooperation is not necessary . . . may be held so far apart that the sharp firm *edges of the teeth define* the orifice of the mouth. For *A*, the angles of the mouth can be drawn entirely aside. For *O* they can be firmly stretched by the muscles above and below them which then feel like stretched cords to the touch, and can be thus pressed against the teeth. . . ."

— HELMHOLTZ (Ellis translation).[1]

We Need More Attention to Surfaces. In this statement, the author sees the finest contribution made by Helmholtz to the subject of vowel production theories. It might well have been here included under the chapter on theories. But for obvious reasons it was kept for insertion at this point. It is unfortunate that Helmholtz did not develop the idea experimentally. He adduced almost no evidence to prove the statements made. His vowel experiments seem to have been limited to proving the Wheatstone " harmonic," Willis " cavity tone," or Ferrein " glottal vibratory " theories.

What Others Have Said. Perhaps this is one reason why vowel investigators have in general disregarded any effect surfaces may have in changing vowel quality. Scripture seems to be about the only one who turned his attention specifically to an experimental study of the effect surfaces might have under certain circumstances. We shall recur to his

[1] Helmholtz. *Sensations of Tone* (Ellis translation), Longmans & Co., N. Y. ed., 1912, p. 114. Italics mine.

contribution below. The above citation, and those given in the chapter on front vowels herein, contain all the information which Helmholtz gave bearing directly on this subject. It will be noted that he made no attempt to apply these facts to any vowel specifically, except in the case of *a* (ah) and *o* (oh). What he says is primarily but a generalization; it is mostly surmise, bolstered somewhat by reference to the varying walls of organ pipes, and the analogous citation of lips, cheeks, throat, and teeth. In making these casual comments, he has of course not been alone. García made such intimations before him, and was somewhat more specific in citing definite vowels, and applying this idea to " tonal " or so-called " placement " quality in general. The reader will see the bearing those statements have, which are herein quoted in the chapter on surfaces and that on front vowels.

Necessary to Further Develop Theory of Surfaces. But now, since neither Helmholtz nor any other scholar, so far as the author can find, has developed this idea of the effect varying kinds of surfaces may have in the production of different qualities in vowels — that is, developed it in such a way as to make it form a subsidiary theory, the author takes it upon himself to do so. He would be much happier if he could leave it undone. It would be far more to his liking if he could merely present the experiments given herein, and that without any comment whatever. For the experiments represent a record of facts; but these attempts to interpret in terms of theories which we lay down can stand as nothing more than mere opinion. Since, however, these X-ray pictures of tongue position and vocal cavities manifest in vowel production throw doubt on some of our traditionally accepted theories, it becomes necessary for somebody to interpret them. However, there is such a mass of material at hand, that it will be impossible to do more than sketch some of the most apparent high lights pertaining to any theory — ours or others.

How Surfaces Change Speech Quality

Surface Vibrations: R, Z, Yod. We know that when the cavity surfaces are so constricted as to present an obstruction to the air current, these surfaces may start vibrations of their own. The tip of the tongue may so function. It does in the case of the Spanish point lingual rolled *R*. Substances in the back cavity may be set into such vibration, as in the so-called " velar " or " uvular " *R* (either German or French). Or

if the air pressure is very great, the surfaces become tense, the opening is decidedly constricted (as by the tip of the tongue for example), and high-pitched buzzing fricative noises may be added to the complex tone originally emitted from the glottis. We produce such a sound in a "*z-z-z*," but it may also be heard in the so-called "palatal yod" — as for example in the first of the two vowels in the word "*yet*." Such a vowel may verge very closely on a voiced fricative, and might well have

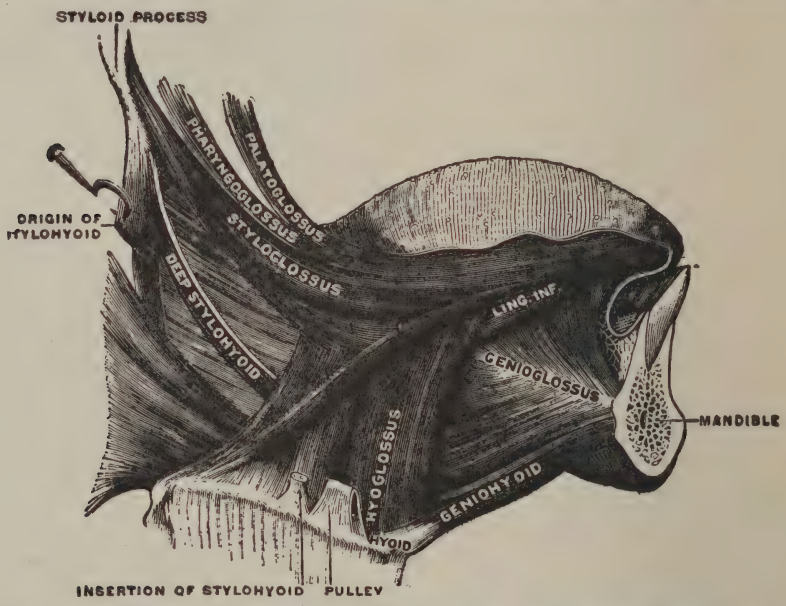


FIG. 9. — MUSCLES CONTROLLING MOVEMENTS OF TONGUE, SIDE VIEW.

been produced by such tongue positions as those in Figs. 58, 62, 131, etc., which are in reality other vowels but show cavities with openings so narrow as to justify the conclusion that under increased air pressure surfaces and saliva might well be started buzzing.

High Pitched Inharmonics. Such buzz or fricative sounds would usually be high pitched, and it is evident that they might be inharmonic to the glottal concomitant which they accompany. Hence they would ordinarily be classified as noises. All that is necessary to produce them is sufficient air forced through to start these surfaces vibrating.

In Front Vowels. The author suggests that some of the quality which distinguishes "peep" (*i*) from "pip" (*ɪ*) or "pape" (*e*) may at times

be due to such buzzing surface vibrations — whether of soft parts or of bony ones. Certainly this is what distinguishes the above mentioned "palatal" *j* (as in "*ye*") from *i* (as in "*eat*"). And but very little more constriction or breath pressure is necessary in order to force more pronounced vibrations, with a resulting passage from *j* (as in "*you*") to ʒ (as in "*azure*"). All that is necessary in order to set up the surface vibrations requisite for such a change is to raise the tip of the tongue. The difference between an *li* and an *lj* (or "palatalized" *l'*) consists in nothing more than these pronounced surface vibrations present in the *i* element of the *li*.[2]

The Crux. There can be no question as to the possibility of interior mouth surfaces being able to create these independent fricative noises. The only question which need concern us is whether they may actually form a part of vowel quality, in an "ee" (*i*) for example.[3]

García. The fact that surface vibrations might be so involved may be one of the reasons why García (and singing teachers generally since his day) has recognized the necessity of opening the front cavity more than would otherwise be usual, when singing the vowel *i* on a note which is high pitched and very loud.

High-Pitched Elements in a Sound. As we have said, such surface noises would manifest very high-pitched characteristics. We know that the fricative *s* carries frequencies as high at least as 7000 or 8000 d.v./sec. These are very considerably higher than the sixteenth partial which Helmholtz mentioned as having heard in the "bright vowel sung by a powerful bass voice."[4]

In the chapter on front vowels we have considered the possible function of the vocal cords in accentuating the high partials for such vowels. Now if a narrowed front cavity functioned actually to add further high-pitched vibrations, it can readily be understood that García's recommendation would be justified:[5]

[2] In his study of linguistic change, the author has commented on so-called "palatalization," and referred to his extensive series of investigations dealing with this question. These he hopes to report at some future time.

[3] The author has heard Prof. Wilfrid Klamroth of New York City, one of the most outstanding voice teachers in the country, demonstrate an interesting parlor trick which bears on this subject. In the presence of Sir Richard Paget and a group of other scholars we heard him make his mouth function to represent three individuals with different pitched voices calling "Mariah!" at the same time. This he accomplished by creating one set of surface vibrations from each cheek added to the one from the glottis.

[4] Helmholtz. *Sensations of Tone* (Ellis translation), ed. 1912, p. 103.

[5] García, Manuel, Jr. *Hints on Singing*, Schuberth, N. Y., p. 12.

"The Italian I" (*i*) "and the French U or German ü" (*y*) "in the head and high chest notes must be opened rather more than in speaking, or their tint would be unpleasant. Carried to excess, these timbres would render the voice . . . harsh . . . like the quack of a duck."

Compensating Function in Vocal Cords. In this connection, the author may mention another interesting observation, made with his laryngo-periskop during the production of the vowel *i* (peep) on a progressively lowering pitch. The tongue position taken to produce an *i* (peep) on a "middle register" glottal fundamental no longer suffices after this latter's pitch has progressively descended to the "lowest register" (somewhere below 125 d.v./sec. in the author's voice). That is to say: in the production of the vowel (*i*) it becomes necessary to narrow the front cavity decidedly, or to increase the energy behind the sound, when the glottal note passes to a very low pitch if its quality is to remain unaltered. If this is not done and the same tongue position required to produce *i* on the high pitch is utilized for the low one, the vowel loses that "metallic" or "clear, ringing, bright" quality characteristic on an *i* (peep) and passes into a vowel quality which in the first stage is heard as *ɪ* (pip). Or when the glottal note descends into the realm of the "growl" (below 80 d.v./sec. with the author's voice), it may even sound like ɛ (eh) or ə (uh). Perhaps the reason for this may be sought in the suppression of the "metallic high partials." At any rate, the laryngo-periskop shows a physiological change taking place during the descending pitch which inevitably produces a "damping effect."

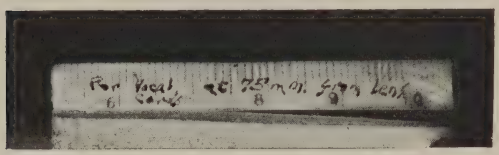


FIG. 10. — SCALES FOR USAGE WITH VOCAL CORD PICTURES.

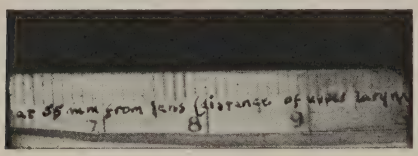


FIG. 11

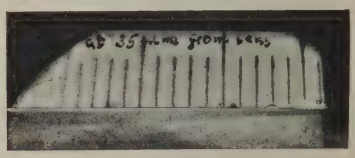


FIG. 12

At this point (125 d.v./sec. in the author's voice) the cushion of the epiglottis comes back so close to the arytenoids as to form (along with the

soft surfaced false cords) a very effective damper of the " soft curtain " type above the vibrating cords. There is left but a small opening of less than 3 mm. diameter through which the sound can escape. Now evidently this deadening function (of these soft surfaces and the inclosed air cavity formed by the ventricles of Morgani immediately below them) is certain to show its first effect on the complex glottal tone in a suppression of the high partials. If it is true that the *i* (eat) has a quality which is " more ringing and keen "[6] than that of the *ɪ* (it) one could expect this damping function of surfaces to cause the transition from *i* (eat) to *ɪ* (it), and this, independently of any cavity function.

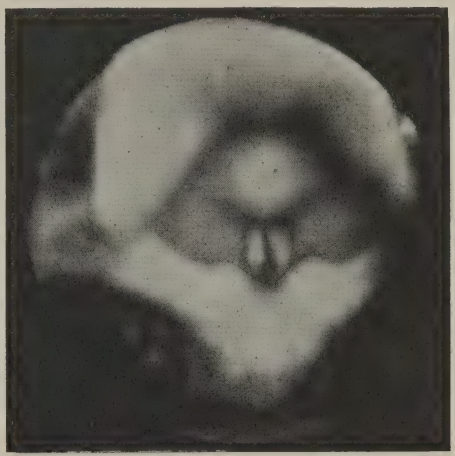


Fig. 13. — Interior Larynx During Normal Pronunciation of the Vowel *æ* (as in " Pap ").

Where the pitch is lowered to its lowest limits and the buccal cavity is left unaltered, the normal ear appears to hear precisely this change in vowel quality. This fact would appear to be demonstrated by the following experiment, in which we tested the effect of a subject lowering the glottal note and keeping the same tongue position, as he progressively passed from a high to a low voice tone on the vowel *i* (ee).

The Experiment. Two rooms isolated from each other were utilized. In the one the subject was placed. It was necessary that he be kept unaware of the purpose of the experiment, and that precautions be taken to prevent him from subconsciously shifting the cavity as we normally do in the course of such changes in pitch. This latter was accomplished by offsetting or preventing the aural control which ordinarily makes this possible by masking the sound he produced with another. To do this hearing tubes were placed in his ears, and a loud continuous (ee) *i-i-i-i-* on a progressively lowering pitch was sounded into them. Thereby his

[6] To use the terminology of Helmholtz. Cf. the quotation with which this chapter was begun. Note that this quality is attributed to "many and powerful upper partials."

reproduction was drowned out in his own hearing, and his ear was thus prevented from perceiving fine distinctions of vowel quality in his own voice. This would thus militate against his subconscious tendency to alter the cavity in order to keep the quality of the vowel constant. His reproduction was spoken into a hearing tube system which led into the next room. This latter was equipped with separate recording niches for 30 observers, and a cut-out which made it possible for the operator to limit any part of a sound he wanted them to hear. By this means the operator could "cut" the observers in, in such a way that they could hear nothing but the high pitch, or the low pitch part, as the operator willed.

FIG. 14. — VOCAL CORD PICTURE FOR VOWEL ɛ (AS IN "PEP").

It is interesting to note that the observers normally recorded *i* (ee) on the high pitch, since this is what the subject was started out on. But when they were suddenly cut-in on the lowered pitch point of production in the vowel the subject thought he was producing as *i* (eat) they regularly recorded *ɪ* (it), or even, ɛ (pet), or ə (th*e*), but rarely *i* (eat).

An Artificial Production Experiment. In Chapter VI we report in more detail another observation which is of decided interest, and is probably not without bearing on this question. We refer to the fact that Sir Richard Paget's ɛ produced artificially with cardboard resonators tuned to 1722 and 406 d.v. per second changed to *ɪ* (pip) or *i* (peep) when its adjusted glottal pitch was raised. Professors Weeks, Gray, Krapp, and a large number of others were present to verify this fact.

Conclusion. If these observations were valid, there would seem to be no question but that they justify the conclusion first, that the same cavity will not produce the same vowel under all circumstances, and is actually known to produce two different vowels each bearing its own

clear-cut identity; second, that the pitch and loudness of the glottal or actuating tone may be of vital importance in determining vowel quality; and that this is true under both the first and second conditions, entirely independent of any change in the walls or in the dimensions of either the cavity or its apertures.

How the Vocal Cord Change Is Offset. On the other hand, in the hearing-tube experiment above cited, if the subject, when he reaches the low pitch (for the author's voice, around 80 d.v. per second), is asked suddenly to raise the tip of the tongue [7] or in other words to constrict the front cavity against the hard palate and teeth, the vowel is no longer heard as *ɪ* (pip) but is regularly recorded as *i* (peep) or, if the tongue is extremely constricted, as *j* (ye) or even *z* (ze) or *ʒ* (regime). Now the normal result of this raising of the tongue tip, whereby the opening to the resonator is decreased, would be to lower the pitch of the cavity. Hence the vowel should change in the other direction towards *e* (pape) or *ɛ* (pep) to fulfill the expectations of the cavity tone theory. One can only conclude, therefore, that the opposite effect is brought about by some surface influence operating on the high partials.

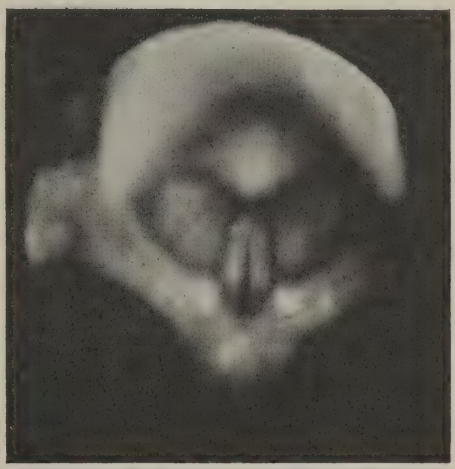


FIG. 15 — VOWEL *e* (AS IN "FAME"). ROUND TOP BUMP IS THE CUSHION OF THE EPIGLOTTIS.

This may be analogous to that manifest in narrow-stopped organ pipes, but since the directly opposite result is produced where constriction is produced by purely soft surfaces, the author is constrained to believe that much of that tonal quality manifest in such front vowels as *i* (eat) can be traced to the effect which the hard surfaces (teeth and palate) have in accentuating the high partials or "metallic" or "ringing" components.

García's Explanation. Apparently García made a general applica-

[7] Compare this with the observation of Dr. E. M. More, *Trans. N. Y. Med. Soc.*, 1872, p. 280, line 27.

tion of this idea of constriction to explain "brilliancy" in the tone. Elsewhere he has said:[8]

> "The tube which surmounts and surrounds" (the glottis) "also greatly affects the quality of the voice; by its contractions it gives brilliancy to it and its widening volume;" . . .

We might think he had in view here a narrowed cavity, producing a higher pitched cavity-tone. But this is evidently not so, since he proceeds to speak of the narrowed epiglottal opening. This would rather lower the pitch of the cavity-tone:

Fig. 16. — Vowel *I* (as in "Pip"). Blunt Edged Vocal Cords.

> "The epiglottis also plays a very important part, for every time that it lowers itself, and nearly closes the orifice of the larynx, the voice gains in brilliancy; and when, on the other hand, it is drawn up, the voice immediately becomes veiled."

Certainly Figs. 22 and 24, showing "pinched" or "harsh tones" (above designated as "brilliancy carried to excess"), would seem to sustain his view.

But if cavity constriction does produce brilliancy, what causes it? Why should a narrowing of openings accomplish the same result? It is evident that in these cases, the quality cannot be attributed to the vibration of the air column in the cavity. That column is the resonator, and is not capable of producing any tones of its own. To put it in Miller's words:[9]

> "The resonator cannot give out any tones except those received from the generator," . . .

Summary on This Point. This latter is in this case the glottis. We are inclined to see two possibilities. First, the friction of the air rush

[8] García, Manuel. "Observations on the Human Voice," *Proc. Roy. Soc.*, London, VII (1855), p. 410.
[9] Miller, D. C. *Science of Musical Sounds*, Macmillan, N. Y., 2nd ed., 1922, p. 176.

may set loose surfaces or saliva to vibrating, particularly where the opening is constricted sufficiently to accentuate the pressure and make this possible. Secondly, a tensing of the walls may not only favor the high partials present in the glottal complex but actually, as we shall see below, raise the pitch of the cavity.

These vibrations of certain parts of the cavity walls may be inharmonic to the glottal actuator, as was intimated above; or, as in those characteristic of the cavity, they may manifest forced vibration characteristics.[10]

Of forced vibrations Miller has said:[11]

> "When the resonator is out of tune with the generator, it is often made to vibrate with the generator, and it is then said to have *forced vibration*. In forced vibration, the two bodies have different natural frequencies, and the resulting common forced frequency is in general not that natural to either body."

FIG. 17. — VOWEL *i* (AS IN "PEEP"). NOTE SHARP EDGED CORDS, AND CUSHION OF EPIGLOTTIS WELL BACK OUT OF THE WAY.

This refers particularly, of course, to the vibrating mass of air in the resonator. But if different types of surfaces lining the cavity are set into vibration, these must inevitably respond with different natural periods, and not only be affected by, but also, according to him, influence the pitches and quality manifest in the vocal cord source, or generator.[12]

Cavity Surfaces. Now the mouth cavity is made up of a good many types of surface: there are the lips, a large number of teeth of different sizes and density, the hard palate, and a variety of soft walls controlled by different muscles and thereby set for innumerable degrees of tension, etc.

[10] Even Helmholtz was brought to admit that the cavity tone in vowels might not be exactly tuned to any given pitch of the glottal complex. Around this question there revolves the controversy between proponents of the fixed and relative pitch or steady and transient state theories.

[11] Miller. *Op. cit.*, p. 177.

[12] Compare West's conclusion as to another type of supposed inter-influence of tones. *Quarterly Journal Speech*, Apr., 1927.

Surface Change in Organ Pipe Changes Quality. They present a cavity wall condition much analogous to that of Miller's organ pipe partly filled with water, only in the mouth cavity there are more varieties of difference with an inevitably less accentuation of one disagreeably outstanding inharmonic. Of his pipe Miller says: [13]

> "The organ pipe partly filled with water" (*i.e.* in his, the space between its double walls) "is like a string unequally loaded, its partials are out of tune and produce a grotesque tone."

Or the condition may be somewhat analogous to (though not so excessive as) that present in a piano where some surface gets loose and is set into vigorous sympathetic vibration by that note or overtone which corresponds to its natural period. We have all heard this disagreeable rattle or buzz. But of course in this case the body is free to vibrate without hindrance. In the mouth, each of these surfaces is heavily damped, so that the effect is not likely to be so pronounced, nor consequently so disagreeable, as in the above-mentioned cases.

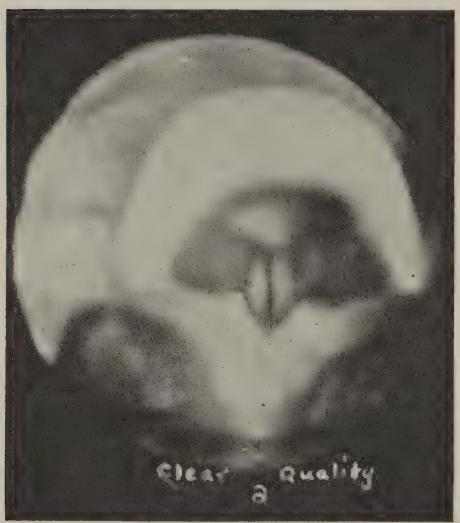


FIG. 18. — THIS ILLUSTRATES THE CLEAR, METALLIC ACCENTED VOWEL ʌ IN "CUT" RATHER THAN THE ə IN "THE."

Similar Speech Cavity Surface Effect. Now the relatively low-pitched glottal tone and its first partials are so loud as to drown out any band of low-pitched sympathetic vibrations produced by soft vocal cavity surfaces which might lie near them; and it is these latter which one would expect to result from the slowly vibrating soft surfaces found in the back part of the throat. So we may conclude that the sympathetic vibration of front cavity surfaces would be of more possible influence on vowel and tonal quality than those found elsewhere. They would respond to the higher pitches. And since they are highly damped because of our

[13] *Op. cit.*, p. 182.

physiological mechanism their effect would not be so conspicuous as to make them disagreeable in the same sense Miller's pipe or the above-mentioned piano is. So we conclude that it might well be that they could function to accentuate the high partials considered to be characteristic of " bright " vowels, " keen " or " ringing " quality, " brilliant " tone or (where excessive) a " harsh " or " strident " tonality—so-called " placement." There might therefore be a difference in vowel quality created by accentuation of high partials through sympathetic vibration. And this might be the quality difference which we have been designating as " closed " in the front vowels, or " open " in the back. The latter is doubtful; the former probable.

What the X-Rays Show. In general it may be said that the X-rays justify this conclusion. Both *i* (beat) and *e* (bait) often show a front cavity which is more closed than for *ɪ* (bit). Compare Figs. 106 and 108 with 107; 117, 119 and 121 with 118; 131, 133 with 132; etc. And the sloping, relaxed condition of the back part of the tongue, as in Figs. 107 and 109, would appear to show that the muscles for *ɪ* (bit) and ɛ (bet) could possibly be more **lax** than the **tense** [14] perpendicular slope for *i* (beet) and *e* (bait) in Figs. 106 and 108.

[14] If this were true, we might call *i* (beet) and *e* (bait) tense, or *ɪ* (bit) and ɛ (bet) lax vowels. But the author would not recommend this terminology, for the simple reason that it is based on unproved theories which experiment may yet overthrow as has been done with the terms "open" and "closed." Acoustic terms are far more reliable. We all know what we hear. So he would prefer to speak of *i* (peep) and *e* (pape) as **bright** vowels and *ɪ* (pip) and ɛ (pep) as their **dull** or dead counterparts. We have dealt with this question more in detail in *The Vowel*, Ohio State University Press, Columbus, Ohio, giving extensive X-ray and palatogram evidence bearing thereon.

PART TWO

PRACTICAL ASPECTS

CHAPTER VIII

WHY CONSTRICTION AGAINST HARD OR SOFT SURFACES CHANGES VOWELS

"*Ringing and keen* applied to a quality of tone, *imply many and powerful upper partials*, and the stronger they are, the more marked are the differences of the vowels which their own differences condition.

"*If the tone of the voice with all its partials* is to meet with a powerful resonance and *come out unweakened, these most flaccid parts of the passage . . . must be* as much as possible *thrown out of action . . . and the passage must be made as* short and *wide as possible*."

— HELMHOLTZ [1]

SOFT SURFACES DEADEN

This brings us to another function surfaces may exercise quite independently of any tones they may themselves arouse. It will perhaps need no proof to justify the assertion that *soft surfaces deaden a tone.*

Echo. If you fling a ball against a hard cement wall, it rebounds, but if you throw it against a soft curtain, it falls. A sound is affected in the same manner. A hard wall flings back an echo, and we kill that effect by hanging soft curtains in front of it. The soft wall deadens the sound.

Speech Deadening. Now it has sometimes been taken for granted that our small vocal cavities would not exercise such an effect. But that assumption is not justified. By actual test we have proved that a sound which is confined and forced to make its exit through even a small soft-walled cavity (three to ten inches long) loses much of its energy. It fails to carry out into space anywhere near as far as one passed through a hard-walled cavity. The latter radiates its vibrations in such a way as to propagate them to a long distance. And loudness is a vital factor in differences in the tone quality of speech.

Reader's Experimental Proof. The reader may perform an interesting experiment for himself which will bear upon this subject. If he pronounces a prolonged *i* . . . . . , and, without moving the tongue, suddenly closes the lips on it, he will be able to note clearly the deadening effect which results — even though he permits a small opening for the

[1] Helmholtz. *Sensations of Tone* (Ellis translation), Longmans & Co., N. Y., ed. 1912, p. 114.

vowel to escape. If this is done on a quiet road at night, it will be discovered that a listener stationed at some distance will have to come very much closer before he can distinguish what is said.

Lip Influence. If the lips are completely closed we get a hum. If left just partially open or almost closed, we may so adjust the cavity as to obtain a perfectly good *i*. Or this *i* may change to the French rounded *u* (as in Fig. 48). (Compare this with Fig. 58.) This latter vowel is probably distinctly less sonorous or energetic than the vowel *i*; it is not so loud, and will not carry so far. Or the vowel may be changed from *i* to an *u*, merely by closing the lips (as is manifest when we compare Fig. 62 with 70). But this *u* has nowhere near the carrying power of *i*. This is probably what Helmholtz referred to in the passage with which this chapter was begun.[2] It is also one aspect of what García referred to in the quotation referred to under note 5 of the preceding chapter.[3]

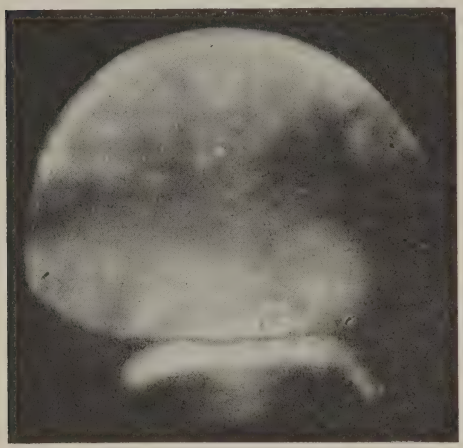


FIG. 19. — VOWEL *a* (AS IN "POP"). NOTE THE TONGUE ALL BUT CLOSES BACK THROAT.

HARD SURFACES ALSO CHANGE QUALITY

The Laws. There is another aspect of surface effect which the author does not find more than intimated in connection with vowel quality. This is all the more surprising when we observe how closely allied it is to the two we have been considering. We may introduce it by a quotation from Miller discussing musical instruments:[4]

> "Both the tones generated by a musical instrument and those reproduced, as well as those absorbed or damped, depend in a considerable degree upon the material of which the various parts of the instrument are constructed."

[2] Helmholtz. *Sensations of Tone* (Ellis translation), 4th ed., p. 114. Original first appeared in 1862.
[3] García, Manuel, Jr. *Op. cit.*, p. 12. Compare with *Traité Complet de l'Art du Chant*, Paris, 1840. *Mémoires of French Academy Sciences*, 1836.
[4] Miller, D. C. *Sensations of Tone*, 2nd ed., p. 179.

Why should this be true? The Helmholtz statement of the law covering tone quality said: [5]

> "The quality of a musical tone depends solely on the number and relative strength of its partial simple tones," . . .

If the walls of the musical instrument alter these factors manifest in partials, surely the vocal organ must do likewise.

How Surfaces Stimulating a Piano String Change Its Quality. Let us consider for a moment some of the means which we know we can make use of in order to change the partials without altering the fundamental. It may be wise to leave the cavity for a moment, and turn first to a consideration of the piano string.

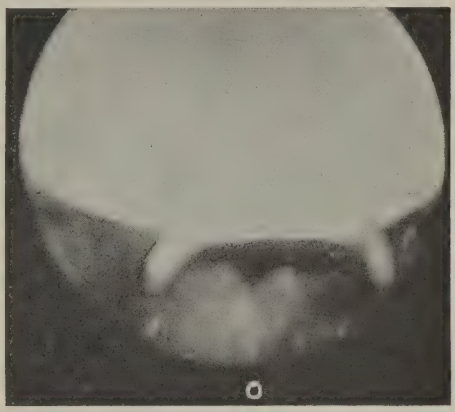


FIG. 20. — VOWEL *o* (AS IN "POPE"). WHITE AREA IS TONGUE. VOCAL CORDS NOT VISIBLE, BUT LOWER THROAT MORE DISTENDED THAN FOR *a* (AH).

We may use exactly the same string, kept at precisely the same pitch and yet produce two tones having entirely different qualities. Helmholtz writes as follows: [6]

> "While . . . the tone can be rendered more tinkling, shrill, and acute, by striking the string with hard" (wooden or metal bodies, or flipping it with your finger-nail) "on the other hand it can be rendered duller, that is, the prime tone may be made to outweigh the upper partials, by striking it with a soft and heavy hammer, as for example, a little iron hammer covered with a thick sheet of india-rubber.
>
> ". . . The effect of the stroke of a hammer depends on the length of time for which it touches the string."

So it may be said that a hard hammer favors the high partials, whereas a soft hammer not only favors the fundamental and low-pitched partials, but may actually serve to wipe out the high-pitched ones. One reason for the latter tendency may be sought in a well-known fact, as follows:

[5] Helmholtz. As cited above.

[6] *Op. cit.*, p. 78. Note that we are not considering the manner in which varying points of percussion or weighting would vary the quality of tone manifest in the string, because the partials present and deadened in the sound are thereby varied.

Why. If I lay my hand on the sounding string, and hold it there, all the vibrations in that complex tone, slow-moving and rapid alike, are forced to come along and encounter its broad, soft surface. Hence they die. The sound is killed. The energy is absorbed. But if I touch the string with the edge of a sharp knife, press firmly, and hold it as long as I like, I do not kill the whole tone. Only those vibrations which have no node or silent point are forced to strike the body and die. A sharp edged metallic or hard hammer rebounds instantly; and even partials whose vibrations are travelling at a very rapid rate do not have time to strike it before it flies back from the string. So we say the hard hammer favors the high-pitched " tin-pan " like partials.

FIG. 21. — VOWEL *u* (AS IN " BOOM "). CORDS VISIBLE AS LOWER THROAT MAY BE WIDELY DISTENDED.

A soft hammer may cling to the string for an appreciable length of time, and so even those partials its percussion stimulates may be reflected back and be forced to strike it and die before it has time to break its contact. Hence we say a soft hammer favors the low-pitched " mellow " partials.

Hard Hammer = Metallic. Where we stimulate the string with a hard hammer, we speak of the resulting complex tone as " piercing," " keen," " metallic," or " bright." [7] It is characterized by accentuated high partials. This is the type of tone we recognize in a " tin-panny " piano.

Soft Hammer = Mellow, Dull. Where we use a soft felt hammer, we produce a complex tone which we speak of as being " rich," " full," " round," " mellow," " veiled," " dull," or " dead." [8] What we do is to deaden its piercing high partials and to accentuate its fundamental and slowly vibrating low partials.

[7] The terms are arranged in their order from high to low — from the least to the most pleasing.
[8] The terms are arranged in their order from high to low — from the most to the least pleasing.

Influence of Sympathetic Vibration. Any surface may vibrate sympathetically and radiate vibrations which correspond to its natural period. But the period for soft surfaces must inevitably be a very slow one. Hence they cannot favor high partials. If Helmholtz, as quoted in the citation with which this chapter was begun, is correct: [9]

> "Flaccid soft walls in any passage with sonorous masses of air, are generally prejudicial to the force of the vibrations."

then there can be no question but that the high, rapidly vibrating partials will be the first tones in a complex whole which will be affected. So we may say that where a complex tone is forced to escape through a pinched-in cavity lined with soft flabby surfaces which enmesh it, it must be radically altered. This would be particularly true where its exit is made up of soft surfaces and is elongated as is that beween the velum and the tongue, Figs. 116, 141, or 171. Where in addition the lips are closed, this effect would be accentuated.

FIG. 22. — NOTE THAT IN TIGHT TONE EPIGLOTTIS CONTRACTS, WHOLE INTERIOR LARYNX TENSES. VIOLENT VIBRATION SHOWN BY FUZZY OUTLINES.

Cavity Surface Effect Analogous. In other words, when we force a complex tone through a cavity lined with either hard or soft surfaces, a simple process of reasoning and a whole group of experiments tell us that when it escapes it will not be the same in both cases. *Soft surfaces deaden*, but *hard surfaces* may *accentuate* the *high partials* in complex tones. So we may expect those **back vowels** (see Figs. 52 and 54) which show decided constriction in soft-walled cavities or their apertures to manifest tonal qualities which we should designate as: **rich, mellow, veiled, dull,** or even **dead.**[10] But the effect of a narrowing

[9] Helmholtz. *Op. cit.*, p. 114.

[10] The terms are arranged in their progressive order from the most pleasing to the least. In both groups this result is brought about by constriction: in the first between soft surfaces; and in the second against hard surfaces.

against hard surfaces, with the teeth bared and the lips out of the way and the throat cavity spread wide so as to minimize the influence of the soft surfaces, as in the **front vowels** (see Figs. 58–61) would be the opposite. The tone produced could be called: **bright, keen, metallic** or even **piercing.**[10] Its high partials would be accentuated in a manner analogous to those manifest in the tone of the piano string struck with a metal hammer.

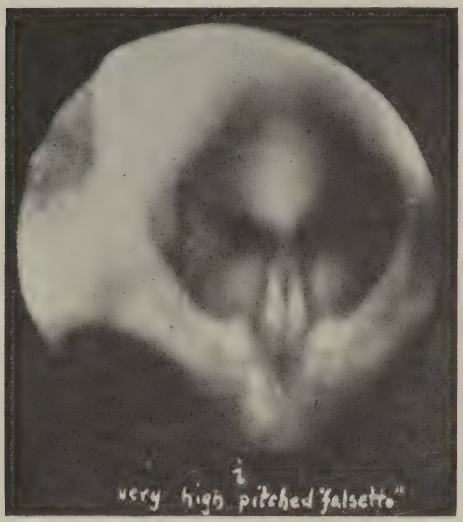


FIG. 23

Independent of Cavity Tone Effect. This of course is independent of the amplifying effect of the cavity air column functioning as a resonator. Heretofore investigators have tended to devote all attention to the effect of this cavity resonator. This may be one reason why we have been unable to reproduce vowels artificially which would be indistinguishable from those of the human voice. The author advances these suggestions merely as postulates worthy of consideration when taken along with those we have heretofore been accustomed to apply; and he would have them considered in connection with the facts pointed out in regard to the function of the vocal cords. For the glottal cord, cavity air volume or varying surface function may one or all be substituted for each other.

SOME EXPERIMENTS

Soft Walls Lower Cavity Pitch. Miller's experience with his double-walled organ pipe is of interest in the bearing it has on this subject of cavity walls:[11]

> "While the pipe is sounding continuously, the space between the walls is slowly filled with water at room temperature. This pipe with the dimensions of a wooden pipe giving the tone G_2 when empty has the pitch F_2 and when

[10] See note on page 65.

[11] Miller. *Op. cit.*, p. 181. Note that the composition of the walls also changes the fundamental cavity pitch. Wood = G^2; air in double walls = F^2; water = E^2. Italics mine.

the walls are filled with water the pitch is E_2; during the filling the pitch varies more than a semitone, first rising, then falling. *While the space is filling, the tone quality changes conspicuously thirty or forty times.*"

It will be noted that the cavity itself was not changed in the least. It was the walls which were altered. And if this alteration in walls produces this astounding change in *tone quality* thirty or forty times why should not an alteration in the walls of vocal cavities also produce changes in tone quality?

FIG. 24. — IN SUCH STRIDENT TONES WHOLE INTERIOR-LARYNX IS SO CONSTRICTED AS EVEN TO HIDE CORDS.

Changing Surface Tension Makes Pipe Squeal. Even one point of changed tension in the walls of one of his organ pipes altered the tone materially:

"Using the single-walled zinc pipe one can produce the remarkable effect of choking the pipe till it actually squeals. When the pipe is blown in the ordinary manner, its sound has the usual tone quality. If the pipe is firmly grasped in both hands just above the mouth, it speaks a mixture of three clearly distinguished inharmonic partial tones, the ratios of which are approximately 1 : 2.06 : 2.66. The resulting unmusical sound is so unexpected that it is almost startling, the tone quality having changed from that of a flute to that of a tin horn."

Bearing on Vowel Theories. Here is a manifestation which may be of decided interest in our consideration of vowel quality, though Miller does not of course so apply it. It will be noted that the change in tone quality was not brought about by any alteration in the volume of air in the resonance cavity; rather it was accomplished by increasing the wall tension at a given point.

Author's Experiment. The author has a lead-tin, round-walled open organ pipe, pitched at $D\#^4$ (615 d.v./sec.) which gives what is probably as passable an imitation of the vowel *a* (ah) as can be had by such mechanical means.

Squeezing Pipe Wall Changes Vowel Quality. If while this pipe is sounding, it is tightly grasped just above the exit [12] (letting it fall into the soft crotch between the thumb and forefinger which are then pressed against it laterally) it speaks *a u — a u — a u* as plainly as any other mechanical vowels the author has heard. At the same time its pitch is not lowered more than a fraction of a semi-tone (not to D^4 581 d.v./sec. by a considerable degree). The vowel quality change must therefore have been due to changed partials. Miller finds the vowel, or cavity tone pitch characteristics of *a* and *u* to be: [13]

a = $D\#^5$ (1230) and B^4 (977 d.v.)
u = E^3 (326).

FIG. 25. — VOWEL FREQUENCIES ACCORDING TO D. C. MILLER.

Crandall gives the " mean characteristic frequency " as: [14]

a = B^4 to C^5 (955 to 1036)
u = $G\#^3$ to D^4 (411 to 581).

FIG. 26. — VOWEL FREQUENCIES ACCORDING TO IRVING B. CRANDALL.

(transposed to Miller's A^3 = 435 for better comparison) while Paget [15] notes:

a = D^5 to F^5 (1149 to 1366) and $F\#^4$ to A^4 (724–861)
u = A^4 to $C\#^5$ (861–1084) and E^3 to $G\#^3$ (322–406).

FIG. 27. — VOWEL FREQUENCIES ACCORDING TO SIR RICHARD PAGET.

So far as the cavity tone for *a* (ah) and *u* (oo) are concerned, it will be observed that in the above figures, the closest approximation would separate them by a rough octave. Yet the pipe only changed its pitch by a semi-tone.

So while there is little characteristic or cavity tone agreement to be found in the figures cited by the above investigators, on whom we must rely for the physical facts necessary for our purposes here, yet there is sufficient data nevertheless to make it evident that any change in the

[12] Much the same result can be accomplished by pinching the pipe just below the lip, in other words, at the points of maximum loudness in the wave length natural to the pipe.

[13] Miller, D. C. *Op. cit.*, p. 260.

[14] Crandall, I. B. *Sounds of Speech*, N. Y., 1925, p. 26.

[15] Paget, Sir Richard. "Artificial Vowels," *Proc. Royal Soc.*, London, 1923. Table found on page 753. His musical notation is figured in Physical pitch, or A^3 = 430.

pipe's vowel quality cannot be ascribed to pitch variations in its cavity fundamental.

Effect on Partials. Hence in terms of the laws previously cited, that vowel quality difference heard in the tone of the pipe must be traceable to partials, other than those two characteristic of the air volume in the tube or in other words to something else besides the cavity tone. And since the *u* (oo) element sounds more muffled or dead, we must conclude without more physical evidence to the contrary that the *mere pinching of* the *pipe walls* at that point [16] *by* the *soft fingers* served to deaden the higher partials; and that as a result of the suppression of those high partials, the vowel quality the pipe conveyed to our hearing was changed from *a* (ah) to *u* (oo). This change was without any doubt due to the effect of wall surfaces, and could in no manner be attributed to any influence whatever of the air volume or capacity of the cavity.

Surface Inharmonics in the Vowel. It is of particular interest to note that Miller says the quality change in his pipe is brought about because of inharmonics. Scripture, Hermann, v. Qvanten, and others have insisted on the possibility of their presence in the vowel. The first two tried to point out that for this reason a Fourier analysis of the speech curve (because it is based on a harmonic postulate) would not be entirely adequate.[17] And Lord Raleigh seems conditionally to agree. It is true Miller stated [18] that the results of his work were in " entire agreement with Helmholtz's theory, and they are, therefore, out of harmony with Scripture's arguments." But when viewed in connection with some of his experiments on musical instruments like those cited, where he proves the inharmonics to be factors in quality change, one would probably be safe in assuming that Miller would not really oppose a theory postulating a similar surface function in creating vowel quality. He perhaps referred rather to Scripture's puff and other theories as opposed to the Harmonic theory.

No Need to Enter Dispute. Such disputes, however, do not fall within the scope of this study, and we need take no side one way or the other.

[16] Note that in each case it is the point of reflection.

[17] Crandall in discussing this type of analysis for his "semi-vowels" makes this admission:

"The evidence justifies the use of the steady-state idea, and the harmonic analysis leading to a determination of characteristic frequencies. But there is a possibility that the harmonic analysis does not tell the whole story." See his "Sounds of Speech," *Bell Laboratory Pub. B* 162–1, p. 34, line 5. Cf. p. 32, lines 7–10.

[18] Miller. *Op. cit.*, p. 217.

But until those who have based their studies of vowel theories on such speech curve analyses reach an agreement it would not seem to be out of place for the author to call attention to the possible implications of these organ pipe experiments — at least in so far as they throw light on the function of cavity surfaces in changing quality.

What Muscles May Be Involved. Such variations of tension at a limited point in the walls of the vocal cavity are perfectly possible. This is particularly true of the walls of the throat. The rôle which such muscles as the *middle constrictor of the pharnyx* might play is of particular interest. Neither should we leave out of consideration the *glossopharyngeus* on either side, or even the wide variation possible because of the numerous fibers of the tongue muscles — especially those of the *genioglossus*, but also the *styloglossus*, and *hyoglossus* on either side, the *inferior* and *superior longitudinal*, etc. They all have a more or less independent function, and the separate fibers of such a muscle as the *genioglossus* are capable of tensing in one part and relaxing in another. Finally, and not the least important (if we may judge by the above), should come a consideration of the possibilities of tension in the *buccinator*, *orbicularis oris*, and other lip muscles, and the effect this might have on changes in vowel quality.

Some Questions Needing an Answer. These pipe experiments raise some experimental questions we must have answered. Miller's organ pipe had thin metallic walls made of zinc. If these walls had been made of thin wood, would a pinching produce analogous results? What if they had been made of very soft and thicker flesh-like material? What if they had been smaller? What if they had been simple resonators made to speak because of glottal action, rather than because of an organ pipe lip action? Would a reed action have such effect?

These are a series of interesting experiments for somebody to perform. They should throw much light on this question of vowel quality. Until that time we shall have to be content to point out the possible effect of such tension on vowel and voice quality, and insist that the influence of the walls may be of quite as much importance as that of the air volume in the cavities in explaining such differences in quality.

Scripture. There is another effect which the varying type of walls in a cavity may have which should not go unmentioned. We quote from Scripture:

"Various kinds of resonators were used, including spherical brass resonators, cubical wooden resonators, resonators lined with felt, resonators with walls of flesh, with walls of water, etc. The water resonators were made by spreading absorbent cotton inside or outside hemispheres made of wire netting and uniting the two halves. Flesh resonators were made by spreading layers of meat over cubical wire frames; the same frames could also be used for water resonators. . . .

"A spherical brass resonator blown by a series of smooth puffs responds loudly when the period of the puffs is the same as that of the resonator."

But (and this is the part of interest to us),

"A very soft resonator, for example, a water resonator," (unlike the metal ones) "responds practically alike to all frequencies of the puffs within a large range." [19]

This is a striking observation. And the author does not find that anybody has yet performed experiments which would disprove it. Unless it is disproved it means that a soft-walled cavity may respond to a whole band of frequencies.

When Miller said that his work was out of harmony with Scripture's arguments, he may have meant that he had repeated these experiments and failed to find the same facts. At any rate these are among the most important experiments which Scripture cited in favor of his argument for the rejection of the overtone theory. However, this probably means, the "fixed" rather than "relative pitch" overtone theory. Scripture uses the following words to give expression to his view: [20]

"Another reason for rejecting the overtone theory lies in the fact that it is based on views of resonance which are not valid for the voice. Helmholtz supposed the vocal cavities to act as a series of resonators which respond to definite overtones in the glottal tone. Such a supposition would be appropriate if the cavities were made of metal or other hard substances. The vocal cavities have, however, soft or moderately hard walls lined with moist membranes. The laws of resonance for soft cavities are different from those for brass resonators. The experiments on resonance show that cavities with soft walls will respond to a range of tone which increases as the softness; . . . The process of vowel production must therefore differ completely from the theory that compares it to the response of hard resonators to overtones."

[19] Scripture, E. W. "Researches in Experimental Phonetics," *Carnegie Foundation Publication*, No. 44 (1906), pp. 113–14.

[20] Scripture. *Op. cit.*, p. 110.

The author cites these experiments as of interest. Scripture uses them as proof of the validity of Dodart's puff theory (which he credits to García and Hermann), and as opposed to Ferrein's glottal vibratory and Wheatstone's "overtone" theory. We need not take sides. But we are interested in noting that Miller found the walls, not the mere volume of air in the cavity to be responsible for the effect in the organ pipes we have just been considering.

Summary

By way of summary, the author may say that it appears to him that in the creation of at least certain "front" and "back" vowel and voice

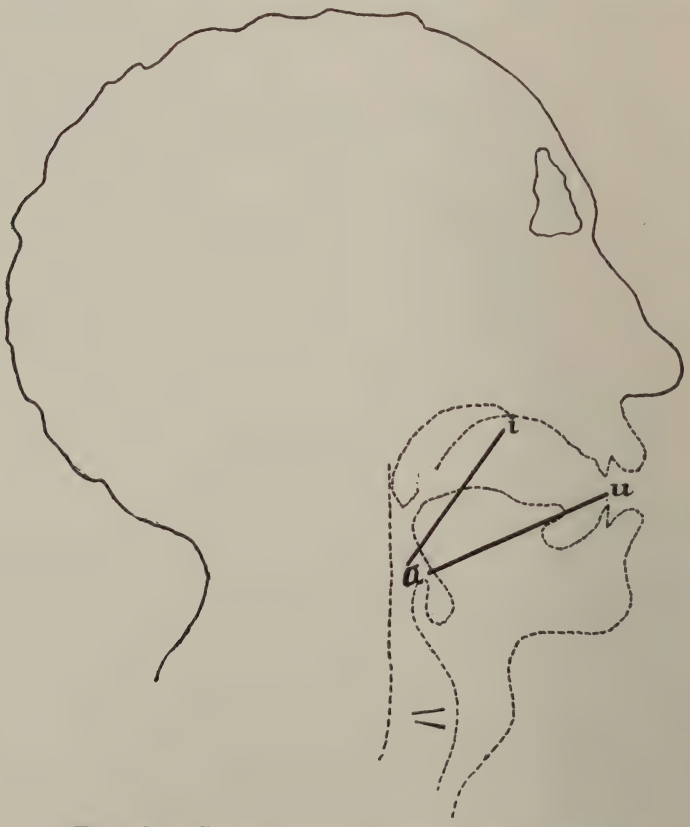


Fig. 28. — Characteristic Vowel Constrictions

This modification of the old vowel triangle might perhaps be justified for a 5-series vowel group: *i e a o u*. The X-ray shows regular and characteristic constrictions at the 3 points indicated above.

quality differences, vocal cord function, and the surfaces and walls in the vocal cavities, may be quite as important as the resonators or rather total volume of air which they contain. It may not be denied that the air volume resonance, or cavity tone, resulting from the influence of the latter, is of importance in changing vowel quality. But there may be other factors such as these surface influences which may be at least partially responsible for fine differences in vowels and tonal or voice quality.

Our disregard of this fact may be partially responsible for our inability to reproduce vowels by artificial means successfully enough to make them indistinguishable from those of the normal human voice.

Front Vowel Effect Classified. It would seem justifiable to conclude that vowels which are produced by narrowing the front cavity against the hard palate and teeth may possibly be due, for:

i; *ɪ*; *e*; ɛ; *æ*

1. To an accentuation of high partials.
2. To an actual creation of independent high-pitched friction tones or surface vibrations.
3. All in addition to the high-pitched cavity tone.
4. To a quality which in consequence of the third factor would be called "high pitched"; and of the first and second either "bright," "ringing," "keen," "cutting" (or even "piercing," "shrill," or "harsh," when loud singing and vocal cord function accentuates the normal effect).

Back Vowel Effects. On the other hand, where a constriction occurs in the back part of the throat, we might expect those soft surfaces to produce in:

ə ɔ: *o U u*

1. A filtering out of the high partials.
2. An actual damping of the energy or deadening of the whole complex tone.
3. And this in addition to the lowered pitch in cavity tone which a constricted aperture leads us to expect.
4. A vowel quality, which in consequence of the third factor would be called "low pitched"; and of the first and second "rich," "full," "mellow," "veiled" (or even "dull" and "dead" when the complex

tone is so badly enmeshed and pinched in as to force it to escape for the most part, through the radiated vibrations of those soft surfaces — in other words when the effect is carried to the extreme).

For the most of these latter vowels it is possible to take a tongue position for *a* (ah) and bring about changes in their quality merely by closing in the soft surfaced lips. In other words a constriction in the soft surfaces of the lips may bring about the same result as a constriction in the soft surfaces of the throat.

Median Vowel. Between these two extremes, the accentuation of high-pitched components on the one hand, and their deadening effect on the other, lies another vowel which partakes of neither one nor the other.

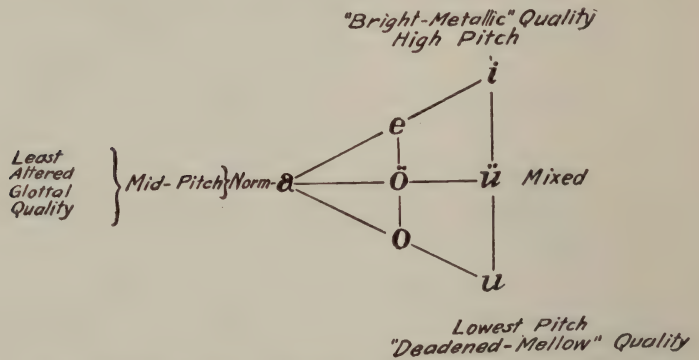


Fig. 29. — An Acoustic Vowel Scheme; the Old Vowel Triangle Modified to Fit the Acoustic Facts.

For this vowel the glottal tone is permitted to escape through a megaphone-like horn from a larynx or generator pulled up as closely to it as possible. All of this permits of it being amplified as a whole with but a minimum of alteration in the loudness of one of its components over that of another. In other words we hear this glottal tone very much as it was when first produced. We should expect it to show very much what the pure glottal tone shows, so we should hear a complex tone in:

a

1. With its high-pitched partials almost unmodified.
2. With its low-pitched partials practically unmodified.
3. With a cavity tone typical of any flaring horn — one which is only heard as having any cavity tone influence on the partials when considered in the relationship it bears to those on either side of it in a series.

4. The vowel quality which results in consequence of the third factor would be called a "middle pitch." The first and second factors, like the third, would justify us in using this vowel as the norm by which we grade the qualities lying on either side.

We never have any difficulty in producing this vowel artificially. Back in 1791 Kempelen [21] commented on two facts which concern it. He said any reed added to any horn would give the vowel *a* and that we interpreted it only in relationship to other vowels on either side of it. He used it as the basic vowel in his artificial reproduction, and created the *o* (oh) and *u* (oo) by narrowing the mouth. But, said he, if I keep my hand over the mouth for some time, what I hear again is *a* (ah).

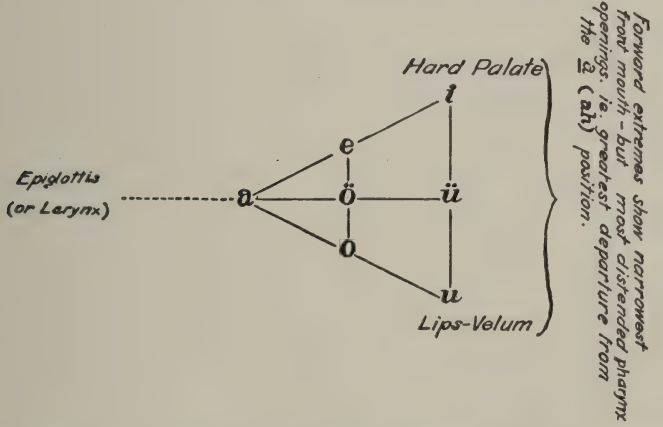


FIG. 30. — THE ONLY PHYSIOLOGICAL VOWEL TRIANGLE X-RAY PHOTOGRAPHS EVEN REMOTELY JUSTIFY.

Scripture, on the other hand, pointed out an analogous relativity for the vowel *u* (oo).[22] He said that if you picked up any very narrow-mouthed bottle and blew across its mouth so as to make it whisper its cavity tone, the large majority of observers (if they did not use some other for comparison) would interpret the resultant as sounding most like the vowel *u* (oo). It is only when you compare the little bottle with the big bottle that the observers begin to differentiate. The author's experiments would seem to confirm this statement.

[21] Kempelen, W. *Mechanismus d. menschl. Sprache*, p. 87.
[22] Scripture, E. W. "Vowel Organ," *Smithsonian Publication*, XLVII (1905), No. 3, p. 360.

Classification

We have therefore three points of demarcation for vowels. They are represented respectively in *i*, *a*, and *u*. Ranged in the order of their highest cavity tone pitches, they are:

i
a
u

If we located them in a physiological scheme we would have something like this (using an adaptation of a traditional arrangement to serve us): [23]

i
e
a
o
u

This scheme should be compared with the facts shown by Figs. 28, 29 and 30.

[23] Du Bois-Reymond. *Musen* (1812). His scheme was used by Helmholtz, and most physicists, physiologists, and philologists, prior to the vogue of the tongue-arching scheme. We modify it here of course.

CHAPTER IX

FRONT VOWELS — SOME LIGHT NOW THROWN ON VOWEL THEORIES AND SCHEMES

"The arrangement of the lips produces one set of vowels, and that of the tongue, another; though, perhaps, few of the vowels owe their formation to either organ *independently* of the other. The labial vowels require an expanded internal channel; to maintain which the tongue is slightly depressed at the root, as the labial aperture contracts; and the lingual vowels require a clear and broad external aperture; to maintain which the lips are gradually elongated as the tongue rises within the arch of the palate. This gives to the vowels from *ah* to *oo* a solemn and sombre character, associated as their mechanism is with a 'long' face and gloomy contraction of the lips; and to the vowels from *ah* to *ee*, a sprightly mirthful character, associated as their mechanism is with a 'broad' face and smiling elongation of the lips."

— Melville Bell (1863) [1]

Bell's Acoustic Facts Correct; Physiological Facts Questioned. To parts of this conclusion of Bell, nobody can take serious exception. The back vowels from **ah** (*a*) to **oo** (*u*) do have a *sombre*, *dull*, or *mellow* quality, and as we have repeatedly pointed out, this is undoubtedly largely due to the deadening effect of soft surfaces such as the lips on the high partials in the tone. The opposite, *sprightly*, *brilliant* or *metallic* quality, is also heard in the front vowels from **ah** (*a*) to **ee** (*i*). Why? Because of variation in the resonating tube length or capacity as implied in the piston pipe experiment of Willis. Bell cites this, postulating: that a short cavity giving a high pitch would be the cause of the quality heard in the **ee** (*i*); and that a much longer resonating tube in the front of the mouth would be the factor responsible in the quality of such a vowel as **eh** (ɛ).

Cavity Width Involves Same Principle. Such is the assumption which has been commonly made. It is true that Bell and many others have

[1] Bell, Alex. Melville. *Principles of Speech*, Hamilton Adams & Co., London, 1863, pp. 26–27. This Bell's father was Alexander, professor of elocution, London, and his brother, D. C. Bell, was professor of elocution, Dublin. At this time Melville was professor of vocal physiology and elocution, Edinburgh University and New College. Later he came to Canada as professor and then to the United States. His son, Alexander Graham, another famous phonetician in the family, was the inventor of the telephone, outstanding teacher and benefactor of the deaf, and founder of the Volta Bureau.

added, as supplementary factors, a certain qualification of increased *width* and decreased *narrowness;* and that for these some have substituted a supposed *tense* and *lax* involvement. But generally speaking these were considered but subsidiary manifestations of the same principle involved in the above postulate.

Crux of the Question. If this postulate were true, we should find proof of it in X-ray photographs of vowel tongue positions among people generally. The question is not whether it would be possible to produce such a progressively changing tongue position as some have assumed; for if the postulated change in tongue position were but a purely incidental manifestation rather than the actual cause of the vowel quality differences in question, the individual could take those positions or not as he pleased, and the actual cause of the difference could be due to something else. So the real question is **whether a progressively changing tube (or opening) is required to produce the varying quality heard in the transition from ee (*i*) to ah (*a*).** The X-ray photographs published herewith definitely answer this question.

Length of Front Tube Not Cause of Vowel Differences. Mere variation in the length of the front resonating tube does not seem to be responsible for differences in front vowel quality. Subject #291 presents a typical case. It will be noted that the point of arching occurs as far back for *i* (Fig. 106) as it does for æ (Fig. 110). The arching takes place well beyond the point where the tip of the tongue feels the soft velum when it is turned back as far as possible. This is farther back than the "mixed-position" we were accustomed to ascribe to the ə (uh) series of vowels when we used the vowel triangle scheme or Bell-Sweet [2] terminology; *i.e.* the "*mixed*" of their "front, mixed back" classification.

Our Traditional Arching Conceptions Erroneous. The so-called indefinite vowel ə, which was credited with the mixed position, classifies rather with the back series, as will be seen by referring to Figs. 169, 139, 127, 113, 53, etc.; and all the front vowels arch well back in the neighborhood of where the mixed, or even where the back vowels, were supposed to arch. Hence most of us who accepted the traditional theories would have been misled if we had attempted the interpretation of these pictures without having had them previously labeled.

[2] Sweet, Henry. *The Sounds of English,* 2nd. ed., Oxford Press, 1910, pp. 24 and 25. See also my detailed study of this problem in *The Vowel,* Ohio State University Press, pp. 245 *et seq.*

This very disturbing thing often happened in the beginning stages of the present study, before the author began recording the sound as it was produced, and photographing on the film as it was exposed, the lead letter representing each sound. If we had been confronted with Fig. 109 (for ɛ) unlabeled, almost any of us would have said it was an ɔ: or possibly even an *o*.

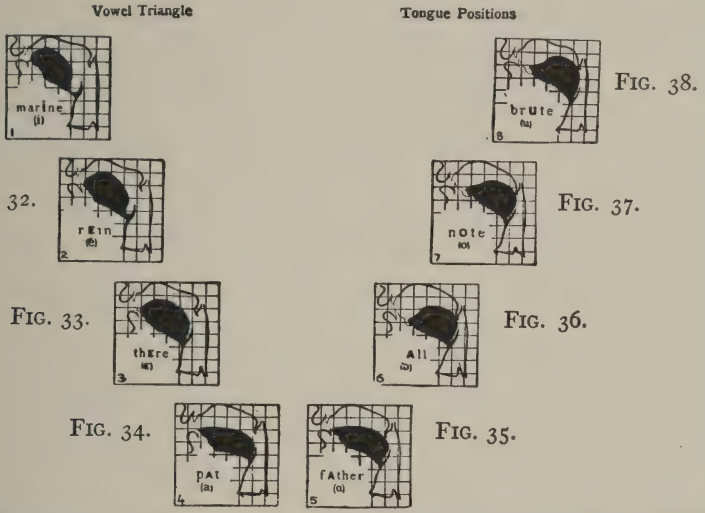


FIG. 31. FIG. 38.

FIG. 32. FIG. 37.

FIG. 33. FIG. 36.

FIG. 34. FIG. 35.

Note. — These diagrams represent the northern English pronunciation of Dr. Lloyd. In southern English the vowel of pat is [æ], *i.e.* the front of the tongue is a little higher, and the tip a little farther from the lower lip (see *Th. Ripman*).

X-Ray Disproves Vowel Triangle. Nor does arching occur along any oblique lines, such as the corroboration of Viëtor's "German Triangle" theory, still probably the most commonly used, would have required.[3] His elaborate scheme is not supported by our X-ray experiments. Stripped of its frills, this tongue-arching triangle is essentially that represented by Lloyd's drawings shown here in Figs. 31–38.

International Phonetic Association Triangle Also Unsupported. Neither can the theory of the truncated triangle which now appears in *Le Maître Phonétique*[4] be considered to receive confirmation; although in the X-rays the point-of-arching line drops down almost perpendicularly from the back part of the buccal cavity where the hard palate be-

[3] Viëtor. *Elemente der Phonetik*, 6th ed., Reisland, 1915, pp. 46, 47, 48, 49.
[4] *Publication of the Association Phonétique Internationale.*

gins, and the arching occurs in essentially the same place for *i* (Fig. 106) as for *ɪ* (Fig. 107), *e* (Fig. 108), ɛ (Fig. 109), and æ (Fig. 110).

Open-Closed Idea Disproved. Nor do these X-rays show that the front cavity commonly gets progressively wider; and any scheme which indicates such quality differences as due to this type of change can at best be said to represent what may be but an incidental or even immaterial manifestation. So far as the diameter of the front cavity is concerned there is more resemblance between *e* and *i* (Figs. 108 and 106), than there is between *ɪ* and *i* (Figs. 107 and 106). It will be observed that for *i* and *e* the arching of the tongue follows very closely the curve made by the arching of the palate.[5] (See Figs. 106 and 108; etc.) This confirms the observation of Meyer[6] made in a comment on his North German. The same fact may be seen in the X-rays of Barth and Grunmach[7] (Tafel 15); in those of Scheier[8] (Tafel VI and VII); and likewise in those of Eijkman[9] for Holland Dutch.

Cavity Size. Elsewhere, we have commented on the fact that the front cavity for *e* may sometimes appear quite as closed as that for *i*. (Compare Fig. 117 with 119 and 121.) Throughout, we note that *ɪ* has a tendency to be more open than *e*. (Compare Fig. 107 with 108; 118 with 119; 132 with 133; etc.) And just as the front buccal cavities for *i* and *e* resemble each other most nearly (compare Fig. 131 with 133), so it may also be said that the cavities for *ɪ* and ɛ are, as a rule, most alike. (Compare Fig. 132 with 134.) This resemblance sometimes runs to almost an exact counterpart not only in shape but also size, if the front cavity alone is considered. Take subject #271 as an example. The sagittal sq. cm. capacity of the front cavity as measured at intervals of 1 cm. beginning at the lip opening shows as follows: *i* 7.7, *ɪ* 14.2, *e* 10.9, ɛ 14.5.

In Cavity Diameter *i–e* and *ɪ–ɛ* Pair. Here it is evident at a glance that the closest relationship commonly exists between *ɪ* and ɛ on the one hand and *i* and *e* on the other. Neither the openings nor the capacities of the other cavities apparently change this relationship materially. However, we cannot jump too hurriedly at the conclusion which seems to be apparent here. The same measurement for subject #291 shows:

[5] Cf. Lloyd and Grandgent. Figs. 60–61, 70–72.
[6] Meyer. *Viëtor Festschrift*, Marburg, 1910 (Elwert verlag).
[7] Grunmach and Barth. "Röntgenogr. Beitr." *Arch. f. Laryng. Bd.* 19, p. 396–407.
[8] Scheier. "Röntgenverf. f. Sprache." *Arch. f. Laryng. Bd.* 22, H. 2, p. 175.
[9] Eijkman. *Vox.*

i 8.2, *I* 13.4, *e* 12.9, ɛ 15.6, or if we eliminate the measurement for the lip opening and that for the teeth which are here included as a part of the cavity (but may be considered to distort somewhat as the jaws drop apart) *i* 6.1, *I* 11.2, *e* 8.9, ɛ 12.8. But this same measurement for the German subject #392 shows: *i* 11.7, *I* 11.6, *e* 12.5, ɛ 15.9, whereas for the French subject #236 it is: s*i* 10.4, l*i*re 12.3, *e* 13.7, ɛ 25.6, f*e*mme 22.2. The soprano #408 gives: *i* 9.9, *I* 14.2, *e* 21.9, ɛ 21.1; the baritone #207: *i* 14.3, *I* 15.8, *e* 21.2, ɛ 30.4; and the tenor #318: *i* 20.5, *I* 20.1, *e* 30.8. My ɛ film for #318 was spoiled and so cannot be given.[10]

It might be well to tabulate:

		i	*e*	*I*	ɛ	*æ*	*a*
American Girl	#271	7.7	10.9	14.2	14.5	26.3	26.6
American Lady	#291	8.2	12.9	13.4	15.6	18.8	24.2
North German	#392	11.7	12.1	11.6	15.9		28.5
French	#236	10.4	13.7	(12.3)	25.6		26.5
Tenor	#318	20.5	30.8	20.1			41.1
Baritone	#207	14.3	21.2	15.8	30.4		23.5
Soprano	#408	9.9	21.9	14.2	21.1		33.8

Apertures Do Not Account for Anomaly. In the graphic chart at the end of the chapter on cavities the apertures are indicated.[11] They do not account for any such differences, so far as can now be seen. The tenor has a cavity for *i* which is greater than that of any of the spoken ɛ's, except that of the Frenchman; and the cavity for the ɛ of the Frenchman is almost twice as large as is that of the ɛ of subject #271. The lip aperture for the Frenchman's ɛ is 19 mm., and the velar 8 mm., whereas for subject #271 the lip aperture is 16 mm., and the velar 14 mm. This makes the discrepancy even more glaring. The Frenchman's back cavity for ɛ is 20.6 sq. cm., that of #271, 12.8 sq. cm. This lowers the Frenchman's front cavity pitch still further below that of #271.

Neither Does Lateral Diameter. It is true that these figures do not show the whole volume. They are measurements in two planes only. But they are sufficient. The discrepancy would be even greater if the whole volume were measured — not such a difficult task since the author has palatograms covering these experiments showing the measurements of the third plane.[11]

[10] All those beginning with subject #392 include the lip and teeth measurement. In that connection we may note that the singers were instructed to open the mouth as wide as possible and sing loudly when their *e* and ɛ were produced.

[11] Cf. measurements given in the author's *The Vowel*, Ohio State University Press. Note that computations may vary depending on what point is chosen as the end of a cavity.

Helmholtz in Error. In general it may, therefore, be said that these experiments do not confirm the statement which Helmholtz and so many others have made, to the effect that the smaller cavities in the woman and child are compensated for by the apertures. And all in all it may be said that there is so little of the uniformity we had expected in these cavities as to rather militate against the conclusion that the volume of air in the front cavity is solely responsible for quality differences in the front vowels. Elsewhere we have given this subject further consideration. In the chapter on surfaces we called special attention to some of these aspects. This was particularly true of the pairs of vowels: *i*, *ɪ*; and *e*, ɛ.

But Acoustically Our "Long-Short" Pairs Exist. That a difference exists is undeniable. For ages, our hearing has been trying to make some such peculiar pair distinction. Even in the days of classic Latin a differentiation was made between "long" and "short" vowels which, while not generally considered to be equivalent [12] to that here in question, is yet curiously reminiscent of our own feeling pertaining to modern vowels. What makes the difference between this *i* (peat) *e* (pate) pair, and the *ɪ* (pit) ɛ (pet) pair, especially when each of the latter is set off in contradistinction to the corresponding one of the first two? It is evident from the experiments cited that the difference in quality is not due to any sagittal tongue position — "open" and "closed" distinction — of the type we have been accustomed to imagine. Neither is it due to a lateral opening.

Acoustic Descriptive Terms Therefore Better. Traditionally we have spoken of these pairs by two other terms. The *i* (peep) and *e* (pape) we have called "tense"; whereas the *ɪ* (pip) and ɛ (pep) have been designated "lax" vowels. This explanatory terminology would seem to be more justified, in view of what has just been pointed out, than that used when the above *i* and *e* are spoken of as "closed" and the *ɪ* and ɛ as "lax" vowels. Both pairs of words would classify vowels in accordance with supposed physiological causes of quality differences heard in them. Justifiably? We cannot so readily refute the "tense-lax" implication, for it is not an easy matter to test such fine variations in, and rapid changes of tenseness in, almost inaccessible small muscles which interlace in their interplay and lie so closely together as to disturb our most care-

[12] See Liddell, M. H. "Stress Pronunciation in Latin," *Language*, June, 1926.

fully planned measurements. The X-ray does indicate an ever so slight justification for the usage of the terminology "*tense-lax*" and practically none for the "*closed-open.*" Some may insist on adherence to established terminology until thoroughly exploded, even where there is but meagre evidence in its favor; and though the author is not one of those who would follow what to him seems a fallacious policy, he has no hesitancy in recommending a preference for the "tense-lax" classification; as there is but the remotest justification, if any, for the usage of the terms "closed-open."

Acoustic Basis a Substitute. However, we do know what we hear. We recognize an audible difference between the pairs. And we may use this known acoustic difference as a basis of classification. This is what Daniel Jones, Secretary of the linguistic Association Phonétique does when he establishes his phonographically recorded "cardinal vowel" standard. No more sensible and scientific criterion or basis of classification and measurement has thus far been suggested.

Acoustic Terminology Substitute. First, the *i* (peep) may be always designated as more "*metallic*" than the ɪ (pip), which is more "*mellow.*" The same thing may be said, respectively, of the *e* (pape) where compared with the ɛ (pep). Second, the Abbé Rousselot and many others have chosen to think of these vowel differences in terms of their whispered entity divorced from the voiced carrier wave. These scholars urge that the whispered vowel *i* (peep) is higher pitched than the whispered ɪ (pip); and no one whose ear is accustomed to distinguish pitch differences will question this fact. Hence the *i* (peep) can be called *high-pitched*, and the ɪ (pip) *low-pitched* with perfect assurance that the designation is entirely justified in scientific fact.[13] On all these points the author has given more information in his *The Vowel.*[14] But there is need in this study for a hurried analysis of the reasons why these vowels may be described in such terms as "*metallic*" and "*mellow.*" This we shall do in the chapter which follows; and the reader will probably do well to give it careful consideration.

[13] See Rousselot, L'Abbé, *Phonétique experimental*, Diderot, Paris, and Liddell, M. H., "Physical Characteristics of Speech Sounds," *Purdue Univ. Bulletin* 16 (Mar., 1924), p. 20.

[14] *The Vowel.*

CHAPTER X

CAUSE OF QUALITY HEARD IN FRONT VOWELS

"If only unevenly numbered partials are present as in narrow stopped organ pipes the quality of tone is *hollow* and when a large number of such upper partials are present *nasal*. When the prime tone predominates the quality of tone is *rich;* but when the prime tone is not sufficiently superior in strength to the upper partials, the quality of tone is *poor*. Thus the quality of tone in the wider open organ pipes is richer than that in the narrower; strings struck by pianoforte hammers give tones of a richer quality than when struck by a stick. . . . When partial tones higher than the sixth or seventh are very distinct, the quality of the tone is *cutting*. . . . The reason lies in the dissonances which they form with one another." . . .[1]

(Vowels are perceived) "by the ear as a very long series of partials belonging to a compound musical tone. With the assistance of resonators it is possible to recognize very high partials, up to the sixteenth when one of the brighter vowels" (such as *i*) "is sung by a powerful bass voice at a low pitch, and, in the case of a strained forte in the upper notes of any human voice, we can hear" . . . (them up to) "the middle of the four-times accented Octave. The loudness . . . differs in different individuals. For *cutting bright* voices it is greater than for soft and dull ones."

— Helmholtz (Ellis)[2]

The Causes of Distinction between "Cutting" and "Bright" Tones. The distinction between "*cutting*" and "*bright*" tones is merely a question of how high these partials have to be to produce their respective qualities. Helmholtz heard up to the "sixteenth partial" in the bright tone of a front vowel sung on a low pitch by a basso. How high is this? We begin counting these overtones from the fundamental pitch of the glottal compound. It is evident, therefore, that the numerical expression would vary as the voice rises or falls. So we must ascertain what the voice pitch was as used in any given case in order to know the actual pitch of the highest partial perceived.

The Helmholtz Case. In the first part of his statement, Helmholtz indicated that the vowel which was sung when he heard the sixteenth partial was on a loud tone. If this had been produced on a possible lowest limit of such a bass range, say *C* below the bass clef, which in Helmholtz's notation would give 66 (d.) vibrations per second, the

[1] Helmholtz. *Sensations of Tone* (Ellis translation), 4th ed., 1912, p. 119. Italics mine.
[2] *Ibid.*, p. 103. Material in parentheses and the use of italics, mine.

sixteenth partial would then have fallen on the three-times accented octave, or the first *C* above the treble clef. This he would indicate at 1056 d.v./sec. The wave for the fundamental would then be sixteen feet long, that for its highest perceived partial would be one foot long.

What the Laryngo-Periskop Shows on Low Pitch. It must be observed now, however, that he would be very unlikely to perceive such high partials produced on the lowest note within the range of any singer. At least the experiments of the author make this seem to be very doubtful. When the glottal fundamental sinks to a pitch below a certain point, which varies with the individual's voice range, the "brilliant" quality of even the most "metallic" vowels gradually shades off. Then, even the vowels *i* (*seat*) and *e* (*sate*) which have a most "ringing," "clear," "resonant" quality turn into their duller counterparts *ɪ* (*sit*) and ɛ (*set*). As a matter of fact, if the pitch is lowered as far as possible, or the air pressure is reduced to a minimum so as to lower the intensity or loudness materially, or if the vowel is shaded off towards a whisper, any vowel we know is so changed in quality as to go even farther and approximate in our hearing the indefinite vowel which we call ə (idea).

Effect of Soft Surface on Vocal Cords. This does not mean that the tongue position has changed any.[3] The difference in quality which the ear hears in this case is controlled by the lungs and air pressure and the vocal cords with the adjoining surfaces which close in over them and thus serve as a damper to create peculiar manifestations of tone quality. As we stated before, the high partials are then killed and the vowel *i* which we started out to produce is then interpreted sometimes as *ɪ* and sometimes even as ə. In both of the latter cases all of its "brilliant" quality has been lost, and without any shift whatever in tongue position.

Pitches Involved. It is unfortunate that Helmholtz failed to record all the aspects of his observation carefully, as he usually did. So we do not know what the voice pitch in this case was. But since we know the facts just cited, we are able to establish the lowest possible limit. In other words, if these physiological observations hold, we narrow down the limits where his basso's fundamental might have been

[3] The author has discussed this fact more in detail in *The Vowel*.

placed; and the indications are that his vowel must have been produced on a glottal tone somewhere around an octave higher than that cited above. This would bring his sixteenth partial up to the beginning of the four-times accented octave (his 2112 d.v./sec.).

Implication. If this is the case, it will be evident that he heard partials practically as high in the normal bright vowel (say *i*) of his basso as he did in the strained forte or " strident " quality mentioned immediately following the " bright " in the quotation with which this chapter was begun. The difference, therefore, must have existed, as he says later, in the relative loudness of these high partials. He further indicated that this might be true, when he stated that if " partial tones higher than the sixth or seventh are very distinct, the quality of the tone is cutting." Yet in his normal bright vowel, cited immediately below this statement, he heard up to the " sixteenth."

By Cavity Tone Resonance? How is this amplified or increased loudness in such high partials accomplished? Is it merely by the resonance of certain cavities? Helmholtz would probably have been the last to extend the resonance theory so far. Will our present-day physicists and others engaged in a study of the vowel insist upon it?

Are High-Pitched Surface Effects Involved? Where in such a production as *i* (ee) the tongue narrows down the front cavity against the teeth and hard palate considerably [4] and the pressure is great as in a loud tone, is there a possibility that friction noises may be created — that is, buzzing noises, if you will, somewhat akin to those we hear in *z* (buzz) and ʒ (azure)? Could the quality produced in a complex tone passed through such a narrow cavity be at all analogous to that resulting from narrow stopped organ pipes, in which the fundamental does not stand out strongly over its partials, and whose tone we designate as the opposite of rich?

Traceable to Vocal Cords. The quality in the " cutting " or " strident " tone has been said to be due to an excessive accentuation of the upper partials in a complex tone. In the " bright " vowel, we know that the high partials are also to be clearly distinguished. In both cases the complex tone originates with the vocal cords. García attributed the " brilliant " quality in the *i* to a " pinching " of the glottis and recommended an exercise passing from this vowel to the others, in order to keep

[4] Cf. chapter herein on surfaces.

their *timbre* from getting too " dark." He also classified them in counterpoise fashion, as follows : [5]

" In the same breath, on the same note, and on each of the vowels a, e, i, o, the student must pass through every shade of *timbre*, from the most open (or clear) to the most closed (or dark). The sounds must be maintained with an equal degree of force. The following table shows what change each vowel undergoes in passing from clear to dark; the process must also be inverted; —

clear	dark
a	approximates to o
e	approximates to eu in French
i	approximates to u in French
o	approximates to u in Italian.

. . . The ringing and dullness are produced in the interior of the larynx. . . ."

Fig. 39. — García's Table

The reader's attention is called to the fact that the *ringing* quality is above definitely attributed to a function of the interior larynx.

"Open" and "Closed." These terms were used by García to describe a type of singing quality the voice teacher understands well. They had for him no such tongue-arching implication as that given them by modern linguistic scholars. He was on safer ground than the latter; for his was an auditory terminology. He heard in the vowel *i* (ee) the most " brilliant " quality of the whole vowel series; and ascribed its brilliancy mainly to a function of the source — the vocal cords, rather than to the resonating cavity. However, he did recognize that the two were interplaying influences on the quality of the tone, which would force it to an extreme and hence disagreeable ultimate, unless the influence of the one factor were eliminated enough to offset that of the other. In order to describe this function in the cavity, he used the term with much the same implications we employ. If the front cavity were not " opened " on a loud high-pitched *i* (ee) he said the tone would become " harsh " and as we have repeatedly pointed out both this " harsh," or " blatant," and the " brilliant " quality of the tone are due to an accentuation of the high partials. So this accentuation can be brought about either in the vocal cords themselves, or by the hard surfaces in the front of the mouth.

[5] García, Manuel. *Hints on Singing*, Schuberth, New York, p. 12. See also, "Observations on the Human Voice," *Proc. Royal Soc.*, London, VII, Nov. 13, 1855; *Traité Complet de l'Art du Chant*, Brandus et Cie, Paris, 1840; and his paper in the memoires of the French Academy (1836).

Comparison with Cause of Quality in Pianos. We recognize an analogous quality difference in piano strings, which we classify as "*ringing*," "*metallic*," or "*cutting*," in contradistinction to "*soft*," "*mellow*," "*rich*," or "*dull*." These differences may be produced on exactly the same string, kept at exactly the same pitch. We recognize the first type or "metallic" quality, when we strike the string with a wooden hammer which stimulates its higher partials. We recognize the second type when we strike it with the usual soft felt hammer of the piano. The high-pitched, cutting partials are then dampened, and the resultant we call a "mellow" or "rich" tone.

Many Differences Due to Hard and Soft Surface Effects. We treated this question more in detail in the chapter on surfaces. There we intimated that the soft back surfaces may exercise a deadening effect on back vowels and the opposite effect on front. Here it may suffice to point out that the two "tense," "clear," "ringing," or "brilliant" vowels (*i* and *e*) both narrow the front buccal opening against the hard palate and teeth, and at the same time, that they open up the back soft-walled pharyngeal cavity to its maximum extent. The latter characteristic seems to be present always, the first, generally. (Study Figs. 96, 97; 101 and 102; 106, 108; 117, 119, and 121; 131, 133; 143 to 149; 162, 164; 58, 62, etc.)

"Metallic" Vowels Narrow Front and Distend Back Cavity. As a matter of fact these two characteristics — the narrowing in front and distension in back — are in varying degree present in the production of all "front" vowels: *i*, *ɪ*, *e*, *ɛ*, *æ* (see, for example, Figs. 131 to 135). They are also present even in the Italian-French *a* (see Figs. 98 and 57). To the author, at least, this observation cannot be without significance, providing it is universally verified.

Real Differences between Voiced Vowels, from Vocal Cords. Any influence of the hard and soft surfaced cavities would have a very doubtful effect, however, if high partials were not already present in the glottal tone. If the reader will whisper the vowels *i*, *ɪ*, *e*, *ɛ* (peep, pip, pape, pep) he may discover that the difference between *ɪ* (pip) and *e* (pape) has almost disappeared. At least it seems so when the author makes the attempt. It is only when a compound vowel is made out of the *e* and moved during whispered production towards *i*, as we normally do in English, that the distinction between the *e* and *ɪ* becomes really clear. When

this experiment was tried on a large number of observers, it showed every time a wide divergence of opinion as to what was heard. It was only when the vowels ɛ and *ɪ* were coupled with consonants and created in word combinations, that the observers approached any semblance of uniformity.

Consideration of Whispered Vowels. If this observation is true it indicates that there is not so much of a distinction or the brilliant metallic quality in the whispered vowels as can be so manifestly detected in the voiced ones. This would seem partially to sustain García in his statement which attributed the " brilliant " quality in the *i* to glottal function:

> " The Italian *i* being the most ringing vowel, the same *pinching of the glottis which gives it its brilliancy* may be employed to give brilliancy to other vowels. Passing from a *ringing* to a *dull* vowel on the same note may also be recommended to improve the latter. Ex.: *ia, ia, ia, ie, ie, ie, io, io, io.*" [6]

Value of García's Observation. Now García was the first scientist to be able to observe the vocal cords in function. He it was who gave us our modern laryngoscope (which all physicians still use in order to make observation of the larynx possible). Then, too, he was the first to study the vowel who may be considered to have had a thorough scientific background upon which to base reliable glottal observations of this type. And he seems to have seen something which justified him in concluding that the function of the vocal cords might lend certain modifications to vowel color.[7] Helmholtz has made similar statements, though those he has made pertaining to the glottis have probably been based on mere guesswork rather than scientific observation:[8]

[6] García. *Hints on Singing*, E. Schuberth & Co., New York, p. 15. Italics mine.

[7] García, Manuel, "the centenarian," b. Mar. 17, 1805, Madrid, Spain, d. 1906, London. After his return to France from the Algerian war, he entered the hopitaux militaires metropolitains for his courses, in medicine and the clinics. With his father — (long famous) Manuel del Popolo Vicente García, he founded when he finished the most famous voice training courses which the world has perhaps had. He it was who trained Jenny Lind, Henrietta Nisson, Mme. Marchesi, Christine Nilsson, and many other such notable singers. Doctors from the world over paid him honor, and several kings decorated him on his one hundredth birthday. Even before his Algerian war experience he journeyed with his father and two sisters to the United States for what became the first famous New York concert tour of European artists. The older of his sisters, María Felicia Malibrán, took Europe by storm, and many maintain she has never had a peer as a soprano though she died at the age of 28. All the world knows Alfred de Musset's immortal "Malibrán." The younger sister, Pauline Viardot, was likewise acclaimed far and wide, in spite of the older's success which might normally have overshadowed her. Her influence in turning Gounod to operatic composition and the affection which existed between George Sand and the noble Pauline are matters of history. From out of this family of geniuses came the famous brother referred to. The undoubted genius and recognized painstaking work characteristic of the group cause us to grant unusual weight to his opinions, and to stress the same for the benefit of the reader who might be prone to minimize the same in comparison with that of Helmholtz.

[8] Helmholtz. *Sensations of Tone* (Ellis translation), 4th ed., 1912, p. 103, Longmans, Green, New York and London. Italics mine.

"With the assistance of resonators it is possible to recognize *very high partials, up to the sixteenth,* when one of the *brighter vowels* is sung by a powerful bass voice at a low pitch, and in the case of a strained forte in the upper notes of any human voice, we can hear, more clearly than on any other musical instrument, those *high upper partials* that belong to the middle of the four times accented Octave (the highest on modern pianofortes). . . . The *loudness* of such upper partials, especially those of highest pitch, differs considerably in different individuals. *For cutting bright voices* it *is greater than for soft and dull ones.* . . . The quality of tone in *cutting* screaming *voices* may perhaps be referred *to* a *want of* sufficient *smoothness or straightness in the edges of the vocal cords,* to enable them to close in a straight narrow slit without *striking one another.*"

Comment of Helmholtz. Here we have Helmholtz making the definite statement that he could hear the high partials up to the sixteenth in the brighter vowels, which includes the *i* (peep) and *e* (pape) we have under consideration. His very singling out of these vowels implies that such partials may not be as outstanding in the duller vowels. And the "cutting" quality in a "strained forte," which he attributes to a glottal function, is strictly in line with García's interpretation of "brilliancy" in the vowel *i.*

"Bright" Quality of *i* Due to High Partials. Both the brilliant and cutting quality, then, is attributed in this Helmholtz quotation to the impression which the high partials give. The strident quality can be said to be due to a mere carrying of the "brilliant" tendency to an extreme. That is, the high partials are accentuated in order to make the tone "brilliant." A greater accentuation, especially of partials higher than those at that critical upper pleasing limit, would then produce a tonal quality which is disagreeable to the ear. García's concept behind the terms "cutting" or "strident" evidently also implies a pushing beyond the "brilliant." He makes this fact clear in the following comment:[9]

"Any *timbre* may be dull or bright. . . . The Italian *i* and the French *y* in the head and high chest notes must be opened rather more than in speaking, or their tint would be unpleasant. Carried to excess, these *timbres* would render the voice respectively hoarse and hollow, or harsh and trivial, like the quack of a duck."

From this quotation, it becomes evident that the maestro conceived of the possibility of overdoing the quality which he had previously com-

[9] *Op. cit.*, p. 12.

mented upon as being characteristic of the vowel *i* (this is, of course, when singing in a loud voice); and when this happened he apparently characterized the tone as no longer " brilliant " but rather as " harsh," or what other vocal teachers call " strident " or " cutting," etc.

Distinction Breaks Down in Whisper. This is probably one of the reasons why reducing the vowels to a whisper alters the front series and tends to wipe out its distinctions much more than it does the back group of vowels. The reader can convince himself that such an evident difference is noticeable in the effect had on the two groups of vowels, if he will whisper the whole series rapidly from front to back: (without staccato effect)

i ɪ e ɛ æ a ə ɔ o u.

How Whispered Differences Are Accomplished. Some compensation for missing causal factors in the front series may apparently thus be accomplished by a variation in the piercing qualities of the friction noises. This would be possible, we know: first, by increasing the pressure; second, by a certain narrowing of the cavity or opening, which accomplishes the same effect; third, by making the attack more abrupt (the latter would bring about a result at the beginning somewhat analogous to the above two); and fourth, by varying the surfaces which line a cavity through which a sound has to pass.

García Referred to Sung Vowels Only. Of course García's statement in the quotation above involved singing only. He said that the cavity had to be opened more in singing *i* on loud high-pitched notes, in order not to accentuate its high partials in the group above the limit which gives pleasing quality.[10]

Common Practice among Singers. In the chapter on cavities, the author has called attention to the fact that this is a common practice among singers. It is not justifiable, however, to jump at the conclusion that in so opening the front cavity the singer produces another vowel. Consider the tenor cited in the chapter on cavities. Even when he sings an *e* or *ɪ*, as he reaches high pitches on very loud notes, his front cavities open wide and the tongue lies flat in his mouth, yet his vowels are in every way as natural as we hear them in normal speech. Any reader

[10] The reader might be interested at this point in turning to the caption quotation at the beginning of this chapter and comparing the observation made by Helmholtz as to the quality manifest in narrow stopped organ pipes.

may satisfy himself as to the ability of many a well-trained singer to open the front cavity wide on the front series of vowels, especially *ɪ*, *e*, ɛ, and *æ* (pip, pape, pep, pap). The tongue will appear to drop as flat in the mouth as in Lloyd's diagram for *a*, Fig. 35. When considered in connection with vowel theories and the cause of front vowel differences, this must be admitted to be an astounding and important observation.

When the Singer Whispers Vowels. An even more striking observation will be made, however, when the same singer is asked to whisper the vowel. He is no longer able to produce the necessary distinctive vowel quality with the tongue lying flat in the mouth. Yet we recognized it clearly in his singing voice when so produced.

Analysis of Singer's Cavity Compensation for Pitch Raise. Since even the singer is forced to close the cavity in the neighborhood of the hard palate when he whispers the vowels, it follows that, at least under such circumstances, the front cavity must be essential. In those cases where the singer was able to lower the tongue and produce good front vowels, certain modifying conditions were observed to be present, at least for the production of *i* (peep): first, the phenomena occurred most characteristically when the vowel was sung on a loud note; second, it was at its best when the glottal or fundamental tone mounted up into the higher pitches of the individual's range. This conforms with what García said in the passage last quoted. He recommended an opening of the cavity on the "head and high chest notes" when singing *i*, in order that its inherently bright tint might not be carried to such an extreme as to become harsh, since vocal cord function naturally makes the high partials stand out more as the pitch rises. It agrees also with what Helmholtz said in the quotation with which this chapter was begun, though it does not follow his general conception as to the cause of vowel differences.[11]

Vocal Cord Pictures Herein. In the laryngo-periskopik experiments herein there is some evidence covering these questions raised by García and Helmholtz. The author, however, does not care as yet to base any conclusions whatever on them. We refer to those experiments in which it became possible to photograph the vocal cords in normal speech and

[11] Helmholtz was a follower of Wheatstone, as are most of our modern scientists; and there are very few of them who would be willing to espouse any deviation from the air volume cavity tone theory. The author, too, feels that this theory is in general true; but the facts as we have noted indicate that under certain conditions there is necessity for at least supplementing this theory.

song, without depressing the tongue, pulling it out, or submitting it to other artificial control, as has been necessary for all experiments heretofore published. The reader will understand this desire of the author's to be conservative. The vocal cord experiments here presented are of but one subject (a baritone) and are in but an initial shape. They can no doubt be depended upon, however, where they confirm what can be otherwise observed with the naked eye.

Analysis of Vocal Cord Pictures. If we note first the " strident " or " pinched " tone photographed in Fig. 24 we see that the whole interior of the larynx is so tense as to be forcibly set into vibration and give vague, fuzzy outlines throughout. This tension is also noted in the epiglottis, which was apparently making every effort to close and was prevented from doing so by the anterior muscles. Both the anterior and the posterior muscles are therefore under tension and pulling against each other. In the end one set of these muscles is certain to get tired and suddenly relax. Then we say the " voice breaks." Since this is on the vowel *i* the resultant is to narrow the epiglottal exit from the larynx decidedly more than is normal. The same tension is noted on the interior of the larynx. It is especially observable in the false vocal cords and the cushion of the epiglottis moving towards the arytenoids. The former actually appear to pinch down upon the true vocal cords and they get so tight that the blood is forced out and they blanch, or show white along their edges, instead of their normal pinkish red.

The result is of course to increase the stiffness of the true vocal cords, which have to work harder. The tone may not be so loud. To offset this, the breath pressure is naturally increased. Hence the edges operating under the influence of these two factors are more likely to strike together with abnormal violence. If the exterior thyro-arytenoid is also tensed the cord becomes hard and tends to be sharp-edged. Then a " clanginess " of quality in the glottal tone may naturally be expected. We consider this manifestation more in detail in a later chapter dealing with interior laryngeal function.

Effect of Upper Cavity Surfaces. As was indicated in the chapter on surfaces, a narrowing down and extension of the pharyngeal opening between the soft surfaces above the larynx may, on the other hand, tend to suppress some of the high partials. We should expect this when singing the vowel *u* (oo). But when the vowel *i* (ee) is sung the opening of

the back soft-walled cavity wide and the narrowing of the front against the hard surfaces of the teeth and palate could well have the opposite effect (see Figs. 62, 72, and 81). So far as this reasoning can be relied upon, García would therefore seem to be confirmed. As already shown, Helmholtz likewise agrees with García on this aspect of tonal quality.

Further Analysis of Effect on Vocal Cords. As to the " brilliant " quality of the *i* (ee) in the mere spoken word, little proof can be offered, for much remains to be done. A comparison of Fig. 17 with Fig. 16 would indicate a difference in the edges of the vocal cords for *i*, when compared with those for *ɪ*. They appear to be more bunched and blunt-edged for *ɪ* than for *i*, where they seem somewhat sharper. Be that as it may, it will be noted that the narrowing of the interior laryngeal cavity in passing from *i* (peep) (Fig. 17) to *æ* (pap) (Fig. 13) is quite pronounced. This can be seen in the approximation of the cushion of the epiglottis to the arytenoids — which makes the vocal cords seem to get ever shorter — and also in the fall of the tip of the epiglottis.

Conclusions. We must therefore reach four conclusions: first, that certain vowels, especially in the front series, may be produced in different manners, depending upon whether they are whispered or voiced; second, that of the latter, the spoken do not necessarily have to be basically distinguished from the sung; third, that a difference in accentuation of high partials may be largely responsible for the difference between the pairs of front vowels which we have been designating as " open " and " closed " but which could more accurately be classified as " high " or " low pitched," " bright " or " dull "; fourth, that the pitch of the fundamental or glottal tone on which the vowel is produced may at times be a vital factor in altering the quality of some of these vowels.

These two latter observations are herein considered more in detail elsewhere since they are rather too complicated and important for us to dispose of in such a brief statement.

CHAPTER XI

EVIDENCE INVOLVED IN ARTIFICIAL FRONT VOWELS — CAVITY TONE THEORIES NOT ALL-SUFFICIENT

"The most convincing proof of a vowel theory would be a reproduction of the several vowels by compounding the partial tones obtained in the analyses."

— D. C. Miller (1924).[1]

Artificial Vowels. We owe some of our earliest experiments dealing with the cause of differences in vowel and voice quality to attempts made to construct automatons which would produce speech artificially. Machines of this type have always intrigued scientists. And each experimenter in this field has been quite convinced of the effectiveness of his own work. But others who have attempted to use these machines have regularly pointed out their failure. This is disconcerting, since if we had actually solved the problem as to what causes differences in vowel and voice quality, we should be able to reproduce them so that they could not be distinguished from the original. But let us recur to this question in a later paragraph, and turn now to some very interesting facts made clear by at least one of these machines.

In the chapter on cavities, the author called attention, with some detail, to a point which definitely proved a certain possible influence of the vocal cords in causing some differences in vowel quality. Here it will suffice to say that Sir Richard Paget's artificial resonator for the vowel ɛ (in men), when its two parts are tuned in to 1722 and 406 d.v./sec., may be made to speak *i* (of peat) or possibly *ɪ* (of pit) merely by raising the pitch of the glottal note. Why should this be true if the vowel quality is due solely to the natural periods of the resonating cavities, whether functioning as separate formants, or as amplifiers of overtones in the fundamental? Sir Richard's vowel chart (see Fig. 5) does not account for this peculiar phenomenon. According to it, in order to produce his ɛ the resonator should conform to a pair of resonances in which the upper

[1] Miller, D. C. *Science of Musical Sound*, 2nd ed., Macmillan, New York, 1924, p. 244.

lies between 1824–2048, and the lower somewhere between 483–574. As it is, the upper resonance barely falls within the lowest permissible limit for *æ*.[2]

Cavity Tone Theory All-Sufficient? Does this not justify us in being wary of a too literal acceptance of the cavity tone theory as all-sufficient? Of course some may object because this was only an artificial vowel, but is one justified in concluding that the artificial reproduction of vowels is but a plaything unworthy of our notice?

No Perfect Artificial Vowels. As before indicated, the author agrees with the general thesis that a perfect artificial vowel has as yet not been obtained. So we might even go further than Miller and say that no theory can be said to have been sustained until a reproduction can be made which will be absolutely indistinguishable from the original human vowel whose components were analyzed. And the author does not fear that he will be successfully controverted when he states that thus far this has in no wise been accomplished. Neither is this opinion based upon sudden judgment, for it has been his good fortune to listen, in an unbiased and as carefully analytical way as he could, to what are probably the most outstanding machines of this kind. This includes those of Helmholtz, Hermann, Rousselot, Koenig, Paget, Stewart, and others.[3] It is said with all due respect to the splendid work of Sir Richard which we much admire.

Back Vowels Easily Reproduced Artificially. Curiously enough, much of the difficulty encountered in an artificial reproduction of vowels has been met in this front series. Everyone who has tried, could produce the *a*. Back in the days of Kempelen, we find him trying to account for the fact that he had so little difficulty with this vowel, yet was forced to labor for years before he could get even an approximate imitation of

[2] It will be noted that there is a material difference between the frequencies he found for the two ɛ resonators. The cardboard spoke on 1722 and 406. But his earlier plasticene models, on the basis of which Sir Richard's chart was constructed, used pitches within the bands from 1824–2048 for the upper and 483–574 for the lower. This discrepancy of itself would seem to argue against a too literal acceptance of the air volume resonating effect or cavity tone theory as all-sufficient.

[3] Some may maintain, as has been done, that this inability is due to the constantly changing entity of the human vowel. But this by no means follows. We tested that factor by stationing a group of observers at a hearing system and cutting in on the human recorded vowel at various points. It could not be observed that in any case there was any abnormality in their perception. What is more to the point, a similar experiment was carried out with a subject placed at the other end of the system and invisible to the observers. It was possible to cut in any place, at the beginning, middle, or end of a prolonged vowel, and the results were very much the same. Where the vowel was clearly spoken or recorded, nobody hesitated to interpret it correctly or to classify it as naturally human. This, as will be seen, is directly contrary to the results obtained with artificial vowels.

the front vowel, *i* (ee). He notes that it was only necessary to vary the size of the mouth-opening to his apparatus in order to change his *a* to *o* and *u*. But not so for *i*.

Good Artificial " ee " (*i*) Baffling. Paget in commenting on his cardboard resonator is also wont to say: " My '*i*' (ee) has a throaty quality and I do not know why." And to the author this *i* does have that " dead " barrel-like or hollow quality we have noted as characteristic of back vowels, and tones lacking the bright high partials.

Helmholtz made the most elaborate attempts but is peculiarly reticent as to the results he obtained. He manifests no enthusiasm or too evident assurance, though he does say he succeeded in getting reproductions, including also the *i*. In comment on Willis, he says: [4]

> " The vowels E " (by which he probably means a vowel like our *e*) " and *i* were also far from accurately resembling those of the voice . . . as Willis himself states, they could not well be distinguished."

Perfect Artificial Front Vowels the Test. We would seem to be perfectly safe, therefore, in concluding that the real test of success in the reproduction proof of any theory will be shown primarily in the ability to create a front series of vowels which are indistinguishable from those in normal human speech, and which clearly show the subtle distinctions between the brilliant and dull vowels of each pair: *i* (peat) and *ɪ* (pit); as well as *e* (pate) and ɛ (pet). Thus far this has not been done. Surely, nobody will feel justified, therefore, in maintaining that the cavity tone theories suffice to account for all quality differences. Otherwise artificial reproduction of the cavity tones in this vowel would give as good results as for all others.

Parrot and Baritone Cavities. We have but one more proof to mention and then we can summarize this study of quality in the front series in a chapter on unanswered questions. We have cited the fact that the palatal cavity for many of these front vowels may appear much larger than we have been heretofore willing to admit (see Fig. 74). We have noted particularly the case of well-trained singers, who can produce these front vowels with the tongue lying flat in the mouth. So far as the author can see, this all stands in direct contradiction to the cavity tone theories. Not that it means a necessity for their complete rejection,

[4] Helmholtz. *Sensations of Tone* (Ellis translation), 4th ed., p. 117.

but merely that it militates against their acceptance as an all-sufficient explanation of differences in the front vowels.

A Parrot's Cavities Small. On the other hand, we know the opposite to occur. The poor little parrot's cavities are so infinitesimally small in comparison with those of a baritone towering six feet four inches, of whom I have a number of rather imperfect X-rays (not published here because the series was not complete), that there is absolutely no comparison between the two. Yet Mr. Baritone and one parrot I know lived next door to each other for many years. From him, Polly learned to call, " Mary." And when Polly calls " Oh Mary ! " even the best friend the baritone has, or if you will, his own mother, cannot tell whether it was the baritone or Polly doing the calling. How does the parrot accomplish this result with his very small cavities? We have here another of these very disturbing questions which must be answered before the cavity tone theories can be said to have been thoroughly established and justified.

More Than Cavity Tone Theories Needed. The author has not rejected the cavity tone theories. He is seeking merely additional facts which may account for some of the phenomena. So far as can be seen at present, García's theory, contained in the quotation above cited, would seem to be tenable. It may go far towards explaining some of the disturbing facts mentioned and unmentioned — such as the case, for example, in which Paget's ɛ (pep) was turned into an *i* (peep) or ɪ (pip), merely by raising the glottal pitch. It may go far towards explaining our failure thus far to reproduce effectively a perfectly human *i* (ee) in mechanical or electrical automatons — either through the exact synthetic reconstitution of the analyzed frequencies in the vowel, by mechanical means such as those used by D. C. Miller, or the electrical as utilized by Stewart, or the plain resonators which served Paget, and others.

CHAPTER XII

SOME UNANSWERED QUESTIONS RAISED BY A STUDY OF FRONT VOWELS

"In this world if you do not say a thing in an irritating way you may just as well not say it at all, because people will not trouble themselves about anything that does not trouble them. . . .

"Man reads his own nature into every ordinance: if you devise a superhuman commandment so cunningly that it cannot be misinterpreted in terms of his will, he denounces it as seditious blasphemy, or else disregards it as either crazy or unintelligible. . . .

"Facts being of all things the most inexorable; he masks them as fast as he discovers them with beautiful ideals; so that now every mask requires someone to tear it off at the risk of being figuratively burnt alive as a cynical iconoclast. . . .

"Yet do not think . . . that what is true can be annihilated by a general agreement to give it the lie."

— Bernard Shaw.[1]

Numerous Unsolved Questions Posed. By way of summary, we may restate some of the questions concerning front vowels which seemed to the author to require an answer. It is hardly apparent how any vowel theory can be thought to be explanatory of vowel phenomena until such questions are satisfactorily answered. They have been considered in this chapter (though but cursorily, it is true), since they were evidently particularly involved in manifestations characteristic of front vowels.

Do the cavities above the vocal cords account for all vowel differences? If so, how does it come about that the parrot with his very small cavities can produce those vowels? How does the singer succeed in producing front vowels with good recognizable quality, when he leaves the tongue lying relatively flat in the mouth and increases the size of the front cavity so materially over that found in normal speech? If the cavity resonance alone serves to account for vowel differences, what accounts for the innumerable differences in singing tone quality? Is there no relationship between what the singer calls a " bright " tone and the quality we recognize in the vowel *i* as " bright "? Are these differences

[1] Selected epigrams.

merely due to the predominance in loudness of the lower resonance or the higher resonance in a vowel pair? Do the vocal cords play no part in vowel quality, other than to serve as a kind of " carrier wave " for, and actuator of, the cavity resonances above them? If so, how does it come about that in the self-same artificial cavity, it is possible to change the vowel from the ɛ (pep) it was designed to speak to an *i* (peep) or *ɪ* (pip) merely by raising the pitch of the glottal note? Why does it become impossible to retain the same cavity and to keep the *i* quality unchanged, when all that is done is to lower the vocal fundamental to the lowest pitch within your range? What makes the vowel then turn into an *ɪ* (pip); or what makes another turn into some duller counterpart? When the loudness of the voice tone is increased, why does this " brilliant " *i* give off a disagreeable and " too cutting " tone unless the cavity is increased in size and vice versa? As seen in the experiments herein, why is it that these front cavities show such wide diversity of dimensions, and lack of constancy, even when the openings are taken into consideration? Why is it that these apertures even fail to account for the wide divergence in cavity dimensions found in the same individual for the production of the same vowel? Can the vocal cords alone vary the number, relationship, and loudness of partials which they may produce? Are they capable of creating sound by more than one kind of vibration process? Are the walls of the cavities, and varying kinds of surfaces above these cords, capable of variously altering the complex tone before it escapes from the mouth? Regardless of the resonance effect would the " narrow-stopped " cavity for front vowels be different from the " open " ones of the *a* (ah) type? Can complex tones having such long wave lengths as those manifest in speech have their partials materially altered by coming into contact with varying constriction between purely soft, or partially hard surfaces such as the palate and teeth, in relatively small cavities like those in the mouth? Would the varying location of these surfaces have any effect?

The author poses these questions, in the hope that they may stimulate somebody to seek definite experimental proof in regard to them. They are not, by any means, all the questions that these experiments raised in his mind. And it goes without saying, that it was a hopeless impossibility for him to seek an answer to each one of them here.

CHAPTER XIII

BACK VOWELS *A* TO *U*

"For *A*, and other like vowels where the mouth is opened wide and for that reason can have but small influence" (on the glottal complex tone), "the intensity of the partials will diminish upwards in their natural regularly progressive way.

"On the other hand, for other vowels, especially for *U* and *O*, the well nigh closed mouth cavity will make itself predominatingly felt. . . .

"The pure glottal tones consist of partials which diminish in loudness as they progress upward; this falling off is most rapid for *u*, and the least for *i*."

— AUERBACH.[1]

Any Lip Position for " ah " (*a*). As a matter of fact, the X-rays in this study show that *a* (ah) may be produced with almost any kind of lip position. And the lip opening of the mouth cavity may be closed quite as much as for either *u* or *o* and still produce a perfectly good *a*. The reader can also easily prove this fact to his own satisfaction, and will no doubt observe that he can actually reduce his lip aperture to a diameter as small as 5 mm., or the size of a pencil, and still produce an *a*. This fact would seem to throw doubt on the importance of the observation made by Auerbach in the first and second paragraphs above.

Any Front Mouth Position for " ah " (*a*). Much the same statement may be made in regard to the position of the palatal or actual mouth cavity. The tongue may even be pressed well up against the palate and take a front position fully as closed as that for *I* (pip), yet the vowel given out will remain an unmistakable *a* (pap). These X-rays show some such differences in tongue position in Figs. 56, 66, 75, 83–86, 98, 103, 111,

[1] Auerbach, F. "Akustik," the second volume of Winklemann, A., *Handbuch der Physik*, Verlag A. Barth, Leipzig, 1909, pp. 693–5. Translation above by the author: "beim *A* und ähnlichen Lauten, wo der Mund weit geöffnet ist und daher wenig Einfluss hat, wird daher das relative Moment überwiegen, und es werden überdies die Partialtöne an Intensität in natürlicher, regelmässiger Weise nach oben hin abnehmen; bei anderen dagegen, besonderes beim *U* and *O*, wird gerade der nahezu geschlossene Mundraum sich überwiegend geltend machen, und der charakteristische Ton bzw. — bei komplizierterer Gestaltung des Resonators — die charakteristischen Töne werden annähernd fest sein. . . . die reine Kehlkopfklänge bestehen aus Partialtönen die nach oben hin an Stärke abnehmen; die Abnahme ist am raschesten bei *U* und am langsamsten bei I."

123, 124, 136, 167. And there cannot be the slightest doubt but that this objection cited in the first paragraph above is applicable to normal pronunciations in all the languages we know.

Flat Tongue and Wide Mouth Not Required. In other words our traditional flat position of the tongue for the vowel *a* (ah) is by no means necessary. But that the flat tongue and wide-open and spread lip position is more or less the rule cannot be denied. The reason is evident.

But Megaphone-like Mouth Aids "ah" (*a*). A flaring, megaphone-like mouth cavity, with the lips out of the way, is conducive to the transmission of such an *a* tone as that postulated by Auerbach above: viz., one that is as nearly as possible a pure glottal complex tone with the intensity of its partials diminishing in the natural way common to such uninfluenced tones, that is, decreasing progressively more and more the higher the pitch goes. We can picture this complex tone, if we represent the fundamental by 1 and its partials by 2, 3, 4, 5, etc., letting the height of the figures represent the amplitude, intensity, or loudness, as follows:

1 2 3 4 5 6 etc.

FIG. 40. — A NORMAL DIMINISHING LOUDNESS SEQUENCE IN THE PARTIALS OF A COMPLEX TONE.

Why. Now of course this does not mean that none of these partials would be amplified. Even a megaphone is bound to have its own natural period. If it were perfectly conical in shape its frequency could be computed from the equation developed by Philbert [2] for conical pipes actuated by free swinging tongues, as follows:

$$n = L\frac{D+d}{D}$$

FIG. 41

where n = frequency
L = length of cone
D = diameter of the mouth
d = diameter of entrance.

[2] Philbert, Ch. *C. R.*, LXXXIV (1877), p. 1154. Check shows not more than 1.5 per cent error.

And any tone falling within the range of this frequency would of course be favored.

1 2 3 4 5 6 etc.

FIG. 42. — AN EFFECT OF PASSING A COMPLEX TONE THROUGH A CAVITY HAVING A NATURAL PERIOD THE SAME AS THAT OF THE THIRD PARTIAL.

Wide Mouth Conducive to Loudness. Aside from this fact a horn of the megaphone type serves, as is well known, to concentrate and thus to considerably intensify the loudness as a whole of any complex tone which may be passed through it. It is therefore not at all surprising to observe that ə, *o*, *ʊ*, ɔː, *æ*, *a*, usually show as the loudest of all our vowels. Both of the above-mentioned facts pertaining to the vowel *a* are manifest in Auerbach's [3] table showing his analysis of the location of the resonance factor, where the fundamental intensity = 1, and the maximum is indicated in black-faced type, to wit :

VOWEL RESONANCE INTENSITY

VOWEL	PARTIALS AT FREQUENCIES													
	128	**192**	**256**	**384**	**512**	**768**	**1024**	**1536**	**2048**	**3072**	**4096**	**6144**	**8192**	**12288**
u U	1	1.2	1.5	**1.9**	**1.9**	1.3	1							
ʊ U	1	1.2	2.2	3.2	**3.3**	1.6	1.1	1						
o O	1	2.1	2.8	7	**7.5**	5.5	2	1.1	1.1					
ɔː Å	1	2.4	3	7.9	**18**	11	9	7	3	1.4	1			
a A	1	1.6	2.2	4	6	**12**	10	8	6	4	2	1		
ɛ Ä	1	1.3	1.5	3	4	**6**	3.5	1.2	1	1				
e E	1	1.3	2.3	3.9	4.3	**5.5**	2.5	2	1.5	1.4	1.3	1.2	1.1	
i I	1	1.2	1.4	2.2	4	4.4	**5.2**	4	3	2.5	2	1.7	1.4	

FIG. 43. — AUERBACH'S TABLE

Relative Intensity of Vowel Series. Fletcher,[4] who studied the relative intensity of the sounds in speech as a whole, found the following results based upon *θ* (*th* as in *thin*) = 1 :

[3] Auerbach. *Op. cit.*, p. 694.
[4] Fletcher, Harvey, Dr. *Bell Technical Journal*, IV (1925), No. 3, N. Y.

RELATIVE INTENSITY OF SPEECH SOUNDS

Vowel	ə	ɔ:	*o*	*a*	*æ*	*i*	*e*	*I*	*U*	ɛ	*u*	*n*	*θ*
Rel. Int.	893	364	330	270	270	270	244	221	164	149	149	22	1

FIG. 44. — FLETCHER'S TABLE

Power and Energy in Vowel Series. Sacia [5] with a transmitter located 9 cm. from the speaker's lips analyzed the power and energy of speech as carried by vowels in terms of microwatts deriving

> " the mean power " (which may) " be obtained by drawing the average power in each vocal cycle and then drawing a smooth curve through the resulting broken line. . . . The chief significance of this mean power lies in the fact that it is the kind of power that would be read by a quickly acting wattmeter; it is likewise proportional to the deflection shown by the ordinary a.c. voltmeter or ammeter or by the volume indicator. The inherent mean power in unaccented (but unslighted) vowels relative to each other "

is as follows:

INHERENT MEAN POWER IN VOWELS (UNSTRESSED)

Vowel	*a*	ɔ	*æ*	*o*	*U*	ə	*u*	ɛ	*I*	*i*	*e*
For Male	50	37	44	33	33	29	27	26	25	33	22
Female	48	50	39	44	40	38	41	31	32	23	30

FIG. 45. — SACIA'S TABLE

But in a comment further on, he says:

> " . . . such rasping vowels as *æ* (tap), ɛ (ten), *e* (tape), have sharp waves and high peak factors . . . the voices with the higher peak factors are those which in the ordinary terminology are said to be " resonant " or " vibrant "; they have the greater carrying power . . . they are rich in the musical sense and are therefore well suited to singing, . . ."

Bearing on Vowel Physiology. These statements would seem in general to sustain the earlier conclusion reached by García [6] in regard to the function of the resonating cavity above the glottal lips which produce the original complex tone, since these vowels *æ* (tap), ɛ (ten), *e* (tape), contract the front cavity. García stated that:

> " . . . by its contractions it gives brilliancy to it, and its widening volume, . . ."

[5] Sacia, C. F. "Speech Power and Energy," *Bell Tech. Jour.* IV, No. 4, p. 634.
[6] García, Manuel. *Intern. Musical Soc. Proceedings*, VII, p. 410.

Our X-rays would seem to lend some support to the above conclusions reached by other methods. The vowels Sacia speaks of as being " resonant " or " vibrant," to use the ordinary terminology, are produced by contracting the cavity, especially towards the front or hard palate. Whereas those vowels which prove to be in general the *loudest are the middle or* a (*ah*) *series of vowels which open the cavity wide in a flaring megaphone-like shape.* Naturally, in the case of the *u* and under certain conditions of other of the vowels too, the lips may close in such a way as to deaden rather than to increase the loudness.

Physiology of Vowels as a Whole

Three Types of Vowels. Physiologically, as we have already stated, vowels may be divided into three classes. These three are represented by

i

a

u

Fig. 46. — Primary Color Analogy Triangle of Lepsius

and would analogically agree, therefore, very closely with the color triangle of Lepsius [7] if the latter were turned on its side; for the other vowels are blended from qualities of these three " as (are) all colors between red, yellow, and blue." So we have divided vowel cavities, or rather grouped them, herein as we find them in the X-rays, according to three or even four general types:

In the **front series,** from æ (pap) to *i* (peep), the pharyngeal cavity is large and the palatal arched, though it is not always narrowed in the sense we had formerly conceived that it would be.

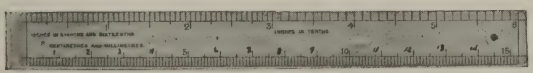


Fig. 47. — A Millimeter Scale Reduced the Same Amount as All Following X-Ray Photographs. To Be Used Therefore in Making All Computations and Measurements Pertaining Thereto.

In the **back series,** including those from ɔ: (aw) to *u* (oo), a very striking constriction of the throat cavity, with a resonator cavity below, is usually to be noted. However, the narrowing of the lips may modify

[7] Lepsius. *Standard Alphabet,* 2nd ed., London, 1863, p. 46. See also *The Vowel.*

this latter peculiarity somewhat, since the narrowing of the lip and velar opening seems to be more or less interchangeable and optional in the production of the vowels *u* (fool) (cf. Figs. 90 and 91 with 54, 130) and *o* (foal), possibly also of ɔ: (fall) (and maybe to a lesser extent of ə (the), and of course of *ʊ* (foot) likewise). For *u* and *o* (and ə or *ʊ*) it seems to be possible to take a tongue position as in "ah" (*a*) or in other words, either to disregard or distend the mouth cavity very radically, and yet produce these vowels, merely by properly adjusting the lip opening.

Analysis. Either the lip or velar constriction (between soft surfaces in both cases) would result in a lowered pitch of the cavity tone, and also

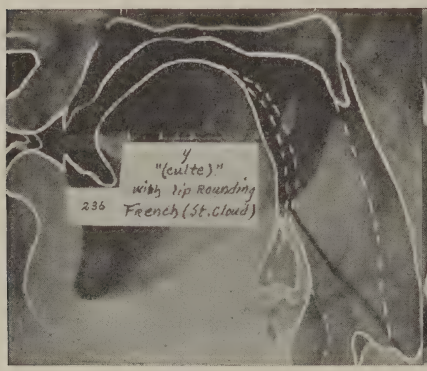


FIG. 48

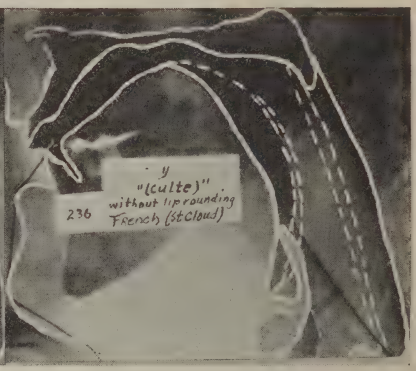


FIG. 49

in a suppression of the metallic quality in the high partials. So here we have manifest one evident type of compensation in the mechanics of normal vowel production.[8]

Then there is the **pivotal "ah"** (*a*) **series,** sometimes referred to as the intermediate series, the production of which commonly manifests no such resonator as is necessary in the production of the *u* (oo) series but a flaring megaphone-like type of cavity. This cavity necessarily begins at the point of constriction between the epiglottis and pharynx because otherwise the back resonator would be created and an *u* (oo) or other vowel in its series would result. It will be seen, therefore,

[8] As a matter of fact the change in lip opening seems to be most common, especially in Spanish and other Romance languages; and this lip manner of production doubtless therefore also characterized the older Latin. If that is true, the lips were more involved than the tongue-arching in the course of the diphthongization of the so-called "open" *o*, for example. So far as the causal factor is concerned, however, these X-rays would lead the author to lean rather to Prof. Sturtevant's imitative or Müller's psychological rather than the current tongue-arching or any other physiological theory.

that the ɔː (aw) is a transition vowel in this pivotal series as one passes towards the *u* (oo) series. The æ (pap) likewise belongs in this middle series as a pivotal vowel in the progression towards the *i* (ee) series.

The **indefinite** or **"uh"** (ə) **series** should really be considered as a fourth, for it cannot be effectively classified with any of the three in the above triangular series. It includes the ə (uh), ʊ (foot), ʌ (tut), and vowels of similar quality in other languages such as some of the French and German rounded or umlaut vowels. This ə (uh) is undoubtedly closely related to the *a* (ah) in that it manifests no back resonator. As a matter of fact

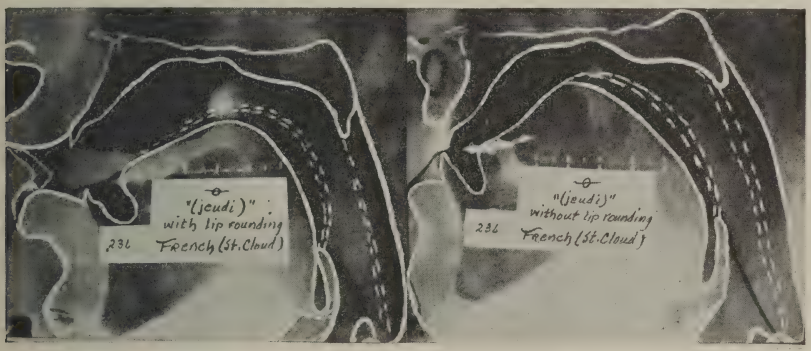


FIG. 50 FIG. 51

these sounds are often mistaken for each other; and the difference may well be sought in a certain suppressive effect brought about by slight modifications of the "normal" reed tone partial series characteristic of the "ah" (*a*). The X-ray shows this "uh" (ə) series to commonly manifest a distension of both the front and back cavity. A lip involvement, usually progressively more rounding as one passes from ʌ (cut), through ə (the, idea), to ʊ (foot), is also regularly indicated. These lips represent soft surface involvement and therefore much the same result can be brought about as by soft surfaces in the back of the throat, hence we naturally expect the ə (uh) to be "mellower" and less "metallic" in quality than the *a* (ah). But both may be said to represent qualities characteristic of artificial vibrating reeds, and they are, in most languages, more or less spontaneous vowels in undirected voicing; the first is regularly heard from a moaning person who is sick and lying on a bed of pain, and the latter from a crying child. The new-born babe in its violent

crying appears, however, to use a vowel quality most nearly approximating the æ (in " mam ").

Difference between "ah" (*a*) and "aw" (ɔː). So far as the other vowels are concerned in these series here treated, however, such an interchange does not seem to be possible. Of course this refers primarily to the possibility of distending the pharyngeal cavity; for even in the case of ɔː this contraction of the throat cavity in the neighborhood of the epiglottis seems to be absolutely necessary; though it is possible to take the *a* position and without any shift whatever in the position of the tongue to change the vowel into ɔː merely by pulling-in and rounding the corners of the

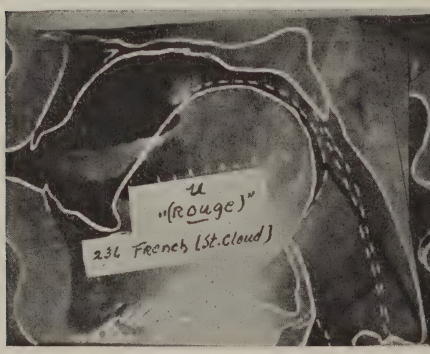


FIG. 52

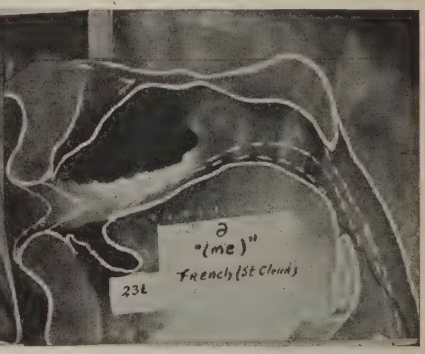


FIG. 53

lips. The change to ɔː without involvement of the lips seems to be accomplished by a still further and lengthened reduction of the pharyngeal opening over that manifest for *a*.

Difference between *a* (ah) and æ (pap). On the other hand, if the *a* is brighter and verges towards æ in quality, which means more distention in the pharyngeal and arching towards the palatal cavity, a lip rounding turns it into ə. This *a* position may therefore be said to be a pivotal one. The position for æ as it generally occurs in American English may be looked upon as the transitional one between the front and back series. It usually manifests a peculiar arching towards the hard palate. It also shows a distension of the upper part of the pharyngeal cavity. These two positions, it will be remembered, were described as characteristic of the front series. But at the same time, æ is usually marked by a very manifest narrowing of the opening between the epiglottis and the pharyngeal walls, a position typical of the *a* series.

This Latter Observation on Back Cavity New. This aspect of the constriction of the back cavity appears to have been totally disregarded up to the present. At least the author has found no description of such function, though now and then some writer has surmised that the throat cavity might be important. This fact is of course not surprising, since we have heretofore had no means of seeing what was going on in this region. Professor C. H. Grandgent[9] noted that he was able to feel with his finger a shift of position between the epiglottis and tongue.[10] He did not indicate, however, the possibility that movement between the epiglottis and pharynx might change vowel quality.

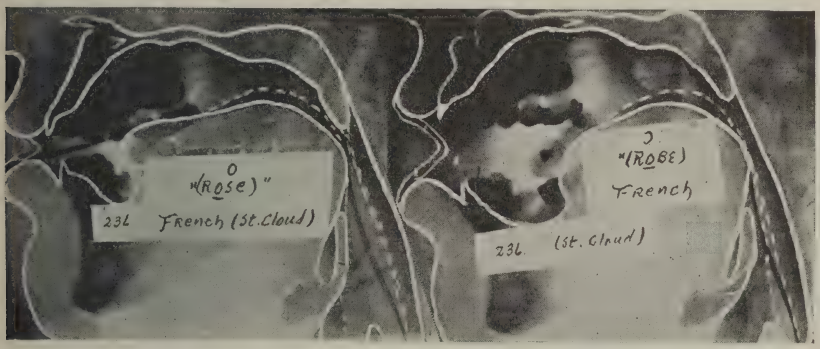


FIG. 54 FIG. 55

Bearing on Vowel Theories. Before the author started the series of X-ray experiments reported in this study, he must confess he would have been considerably perturbed by such an observation. In terms of the cavity-tone theory, no explanation is apparent up to the present. Perhaps this fact throws light on the anomaly of some of the unexpected cavities and tongue positions seen in many of the experiments herein. Yet it must be remembered that, except where otherwise noted, all the X-rays for a given subject were made on the same voice fundamental, controlled by sounding it in the individual's ear during the X-ray exposure.

Confirmation of Others. According to Marichelle,[11] three distinct regions of the mouth are used in forming vowels: 1, the anterior tongue-

[9] Grandgent, C. H. "Vowel Measurements," *Pub. Mod. Lang. Assn.*, CXLVIII (1890). *German and English Sounds*, Boston, 1892.

[10] This subject is treated in the chapter on the larynx.

[11] Marichelle. *La parole d'après le tracé du phonographe*, Paris, 1897, p. 27.

palate cavity; 2, the posterior cavity; 3, the lip opening. Of these he considers the posterior cavity the most important. Into it the vibrations of the vocal cords pass first, after they leave the larynx. This fact would inevitably accentuate its function as a resonator, though there might be other factors which would diminish the advantage it would thus have. Where it gradually flares, after the manner of a megaphone or phonograph horn, the effect on the tone may be accentuated and as stated this may be the principal reason why the *a* is usually spoken of as our loudest vowel.[12] Figs. 123, 136, and 111 for English subjects, or Fig. 56 for French, Fig. 103 for Spanish, and Fig. 167 for German subjects show that this flaring position is one which is commonly taken for *a*. Such a char-

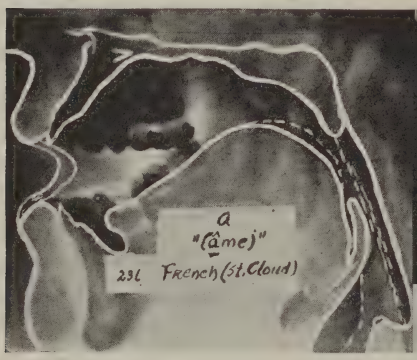


FIG. 56

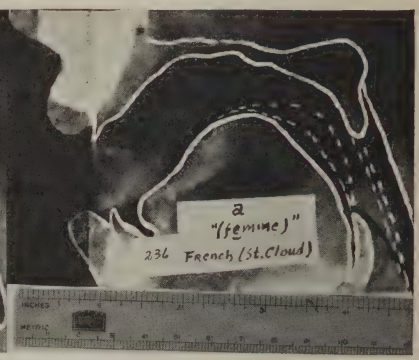


FIG. 57

acteristic shape of the buccal chamber may be more evident in a well-trained singer, who makes an effort to give out a fortissimo or very loudly sung note. At least this seems to be the case in Figs. 66, 75, and 84. In such cases, there results a striking enlargement of the front cavity, as may be seen by comparing Figs. 183 and 84, 85 and 86. As a matter of fact we may see such a discrepancy in size manifest in the speaking-voice cavities. A comparison of Figs. 123 and 124 will show this to be true.

Certainty That Differences in Tongue Position Represent the Same Vowel. Since for all of these X-rays the resultant vowel is recorded, it becomes possible to listen back to the record and hear what quality the vowel had at the time each X-ray picture was taken. Both the record

[12] Cf. Sacia's study cited in quotation given above.

for Fig. 123 and that for 124 are heard as normal West American *a's*. Those accustomed to the current terminology of " open " or " closed " do not hear one as more " open " than the other. Vocal teachers sometimes speak of 124 as having poorer tonal quality than the other, though there is no hesitancy in classifying each one as a characteristic vowel *a*.

Significance. This is one of the facts which led the author to suspect that the size and shape of the front buccal cavity might not be of great importance in changing the quality in back vowels. These X-rays seemed to indicate the constriction in the pharyngeal cavity to be of more importance, so it was deemed wise to test the effect of the elimination of the front cavity. This was done as follows :

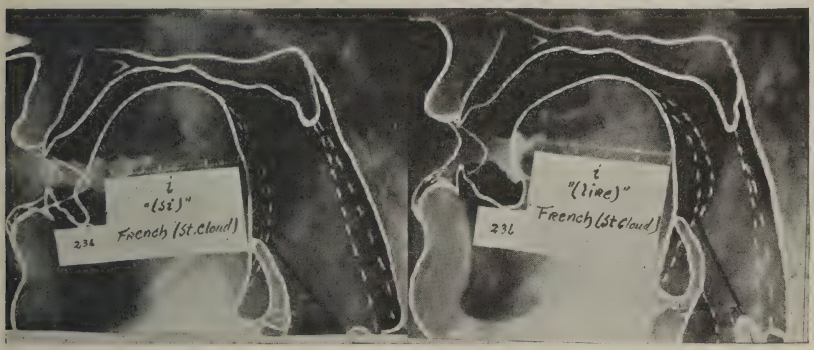


FIG. 58 FIG. 59

An Experiment. We first attempted to extend the front or buccal cavity in order to see if we could thereby change one of the back vowels into another. Comment has already been made upon the fact that it is possible to take a tongue position for *a* and by closing the lip opening change the vowel first into *o*, then with greater closure still into *u*. This fact has been known for some time. It has been explained by saying the decreased aperture lowered the resonance period just as effectively as if we had lengthened (or increased the capacity of) the tube. If this theory were correct, an extending of the length of the front cavity for *a*, should change it to an *u*.

How the Front Cavity Was Changed. In the subject used, the palatal cavity was normally about 10 cm. long by 2 cm. diameter. We placed hearing tubes in the subject's ears and started sounding therein a prolonged vowel *a* in order to drown out his pronunciation in his own ears,

so that he might not be so influenced as to subconsciously alter his pronunciation when we placed the extension to his lips. A mouthpiece was first placed over the lips so that the opening would be reduced to exactly 2 cm. and the subject could adjust the vowel to an *a* with such a diminished opening, before we started. Then as he pronounced, we moved the tube up to and away from the opening. This extension was of hard but water-impregnated clay, 30 cm. long by 2 cm. diameter. This made the front cavity 40 cm. long instead of 10 cm. — its normal length.

Change of Front Cavity Did Not Modify Back Vowel as Expected. The vowel was deadened; but it did not turn into either *o* or *u*. If it

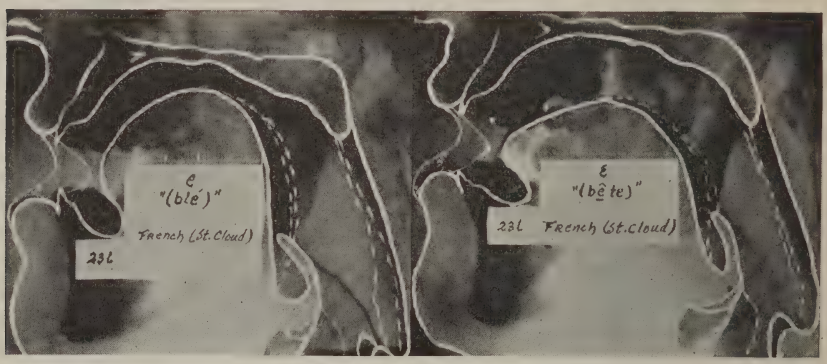


FIG. 60 FIG. 61

could be said to have changed its quality to that of any other known vowel, it would apparently most nearly have approximated ə. Yet we had made the tube four times as long as it was originally. This should have lowered the resonance of the vowel quality in like proportion, but it failed even to make it as " dull " as the vowel *u*.

A like tube 10 cm. × 2 cm. was then tried. In terms of organ pipes, its addition should be tantamount to closing the opening entirely or rather to the conversion of the original palatal cavity into a closed, instead of open pipe. The vowel quality remained practically unaltered. It was still an unmistakable *a*.

Another Experiment. We then constructed a flexible rubber elbow to attach over one end, so that this latter would just fit snugly into the pharyngeal cavity when the tongue took such a position as that in Fig. 84. The palatal cavity around this clay tube was stuffed with various

sound-deadening materials so as to eliminate the resonance effect of this front buccal chamber. Even after this was done it was found that the subject could pronounce all of the back vowels with their clearly distinguishable qualities we know so well. This was an astounding and somewhat disturbing observation. It was the same as saying an individual could dispense with the front mouth cavity and still produce the back vowels.

Marichelle. It was not until some time after these experiments were performed that the author learned by accident that they but confirmed earlier and similar experiments by Marichelle.[13] His work is not easily

FIG. 62

FIG. 63

available, and even at the present writing is not at hand. We may, however, quote at length from Scripture,[14] who protests his conclusions:

"Marichelle maintains the following theses: A. The capacity of the buccal resonator does not exercise a characteristic influence on the pitch of the vowels. The statement that the mouth cavity in front of the elevation of the tongue has no influence is based on an experiment in filling the cavity of the palate with wax and finding that the vowels *O* and *O U*" (our *u*?) "can still be pronounced. Compensation for the size of the resonating cavity by change in the lip opening is avoided by forming the opening in a card placed before the mouth. These experiments seem to me too inaccurate and so contrary to our knowledge of the action of resonating cavities that we cannot accept them. . . . B. The dimension of the lip opening constitutes only a general vague and unstable indication of the vowel. C. The separation of the jaws does not sufficiently characterize the vocal sounds. D. The displacement of the tongue forward or backward furnishes no pre-

[13] Marichelle. *La parole d'après le tracé du phonographe*, Paris, 1897, p. 27.
[14] Scripture, E. W. *Yale Psychological Studies*, VII (1899), p. 90.

cise and essential information on the character (timbre) of the vowels. It is possible to produce all the vowels with practically any position of the tongue. 'Here again the physiological description, as comprehended generally, gives only accessory facts and no characteristic ones.' The three statements are true in a vague way but they do not prove that the vowel character is independent of these factors; the vowels undoubtedly depend essentially and directly on them. Marichelle's point, however, seems to be that the essential factor is the size of the resonance cavity and not its exact form; and in this he is presumably correct.

"According to Marichelle three distinct regions of the mouth are used in forming vowels: 1. the anterior tongue-palate cavity; 2. the posterior tongue-palate cavity; 3. the lip opening. The characteristic tones are

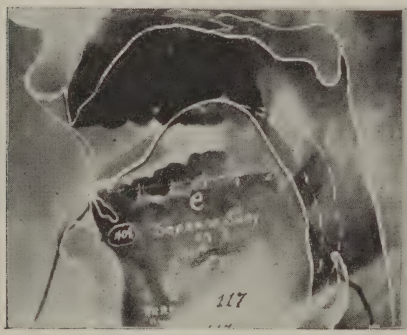


FIG. 64

FIG. 65

modified by *a.* the nature of the walls, whether soft or hard; *b.* the capacity of the posterior resonator; *c.* the degree of opening of the tongue-palate orifice; *d.* the lip opening.

"Marichelle seems to be quite correct in insisting on the importance of the posterior cavity; it is the one into which the vibrations of the cords pass immediately and it undoubtedly acts as a strong resonator. It would be somewhat rash, however, to say that the most prominent resonance vibration comes from this cavity. It may be suggested that the vowel is a complex of resonance tones of which the pharyngeal tone would be one, the anterior mouth tone another, and so on."

Marichelle's Experiments Confirmed. As stated above, the author knew nothing about these experiments of Marichelle. Yet it appears that the present series confirms his conclusions in regard to the back vowels, and in every respect mentioned in Scripture's interpretation. It appears that our experiments here stand in opposition to Scripture's argu-

ment, though in many other matters they have confirmed his viewpoint. The latter's protest seems to result from his feeling that the cavity tones are entirely responsible for changes in differences in the quality of vowels. Yet his own treatment of vocal cord function — varying the type of puff to determine the effect that this would have — would seem to indicate that he did not hold such a viewpoint. It may well be that Scripture's views changed somewhat, in the interim between the publication of his two works in question.

Interpretation. In the chapter on surfaces we have treated our conception of this question more thoroughly. If we have there seemed to minimize the rôle played by the cavity tone, it was not so intended.

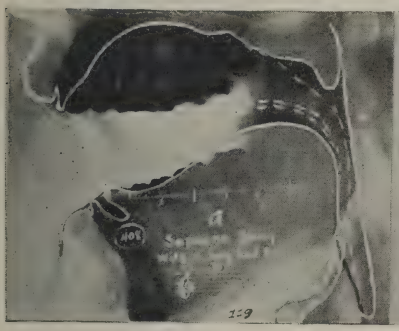


FIG. 66

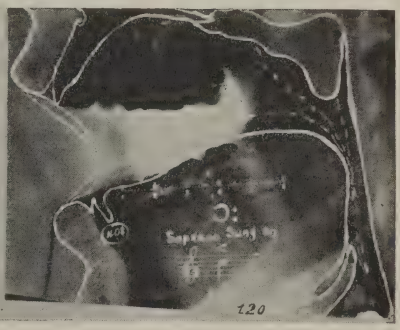


FIG. 67

This comes, probably, from laying more than usual stress on a fact so often slighted, for there is no question in the author's mind but that too little attention has been paid to the effect of surfaces on voice and vowels. We have tried to point out what that effect may be. We have made a special effort to show that constriction in the throat, which is lined with soft surfaces, would not only deaden the whole tone, but exercise a most profound influence in a damping and killing of the high partials which would be progressive in its effect from *a* to *u*. We have also intimated that the characteristic position normally taken for *a* (ah), with its flaring megaphone-like cavity as in Fig. 103, would be most likely to permit the true glottal complex tone to escape with the least amount of modification, whereas a pharyngeal distension and an arching towards the hard palate as in Fig. 110 for *æ* would inevitably tend to produce metallic characteristics which are more typical of the front vowels.

The Sound-Deadening Region. We have indicated that the region where a constriction could occur which would be most likely to enmesh and kill the sound (especially its high partials) would be in the neighbor-

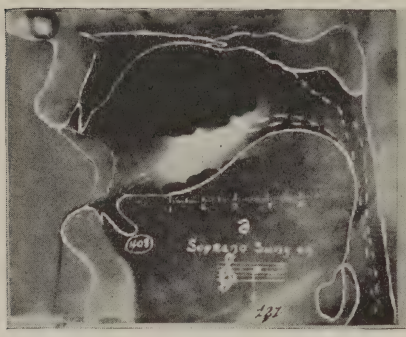


FIG. 68

FIG. 69

hood of the pharyngeal arches — *i.e.* the glossopalatine and pharyngopalatine arches as they pinch in, horizontally and perpendicularly against the tongue. Now it so happens that a pinching in at this point also makes possible the production of the lowest back-cavity tone obtainable. Both the out and the down movement of the larynx aids in distending this back cavity. This striking combination, manifest in such X-rays

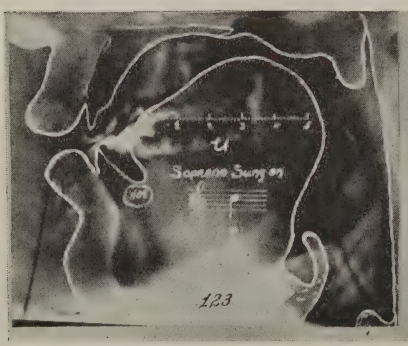


FIG. 70

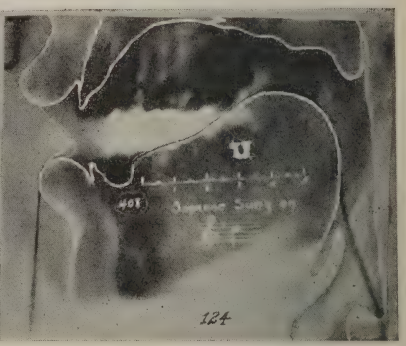


FIG. 71

as Fig. 52 for *u*, cannot be without significance. Neither can the extraordinary reduction of the front cavity in Fig. 70 for *u*. The front cavity there is practically the same size as in Fig. 62 for *i*. The appar-

ent difference between the two may be seen in the lip opening and in the constriction of the linguo-pharyngeal arch.

Function of Lips and Velum Compensatory. We have said that these two openings seem to be interchangeable. If the function of the back throat is eliminated the same result may be accomplished by the closure of the front lips. If the effect of the decreased lip opening is eliminated, practically the same result may be brought about by a decrease in the throat aperture. This statement is not new, but its application may be; and many may protest the conclusion we are now to draw. Nevertheless the author feels safe in saying that a comparison of Fig. 62 for *i* with Fig. 70 for *u* (showing practically the same front position of the tongue for one as for the other) justifies the conclusion that a front tongue position can be taken for almost any vowel and an *u* may result if the lip opening is properly closed.[15]

Umlaut Vowels. This brings up the question as to what causes the "umlaut" vowel. The author must be content for the present to publish his umlaut experiments without comment. They are given in pairs, with and without lip rounding. Each one is heard with perfectly good quality. It will be noticed that in these, an extraordinary back cavity is sometimes manifest, particularly where the lip rounding is eliminated as in Fig. 157.

Summary

Back Throat, Not Front Mouth, Vital in Back Vowels. So far as the author is concerned, therefore, he will hereafter seek for an explanation of the quality of back vowels in the back cavity of the throat, and he will look upon the front cavity and tongue position as more or less unimportant. That the front cavity may produce a characteristic tone conforming to its natural period is undeniable; but these experiments make it appear that this tone can vary within quite a wide range for some of these vowels, or be practically the same for two or more of them without vitiating the vowel quality we have come to recognize as distinguishing them. The influence of the surfaces may partially account for this effect.

Bearing on X-Rays. Certainly this turning of attention to the throat cavity for back vowels solves many problems. Take the French subject #236, for example. The capacity of the front cavity is essentially the

[15] Is this what Marichelle had in mind?

same for Figs. 52 and 54, being *u* and *o* respectively, but the throat cavity for *u* in Fig. 52 is materially greater than for *o* in Fig. 54. And it will be noted that this decrease of the throat cavity is fairly regular in its progression through *u*, *o*, ɔ, *a*, in Figs. 52, 54, 55, 56, respectively. The ə stands somewhat aloof by itself, manifesting less constriction, and hence less of a tendency to enmesh or to dampen the complex tone (or its high partials). It may be said, however, in passing that this latter vowel does not always manifest this quality.

PART THREE

HINTS ON USE OF THESE X-RAY PHOTOGRAPHS

CHAPTER XIV

X-RAY PICTURES AS AIDS TO THE DEAF

"We have not much expert testimony in print from the psychologists. They have used the deaf illustratively to prove their own points, but none of them . . . has yet studied the deaf with the main purpose of *benefiting the deaf*. That is what we want to do, just as far as our zeal and our abilities will permit us to be of real service to them and to their class future."

— Sarah Harvey Porter (1912).[1]

"The *a* ('ah') is the foundation or basic vowel in all languages. All children give utterance to this vowel first, because it is the easiest. The position of all vocal organs required in its production is the most natural, comfortable and unhindered, namely:

"1. The vocal cords vibrate.
"2. The tongue lies loosely.
"3. The teeth are not necessary.
"4. The lips are wide open.

"This sound could be produced perfectly well by anyone who had no tongue, no teeth, and no lips. That is the reason it can be so easily imitated by artificial instruments.

"I found that any pipe, large or small, which I stimulated always gave an *a* ('ah'). It merely changed its musical pitch, which it spoke as now high, now low, depending on the relative size of the pipe, but it always remained an *a* ('ah')."

— Kempelen (1791).[2]

a ("ah") in "bah" or "alms"

An examination of the pictures herein will show that in this vowel the tongue is invariably so relaxed that it lies well back in the throat and leaves an opening no wider than a pencil between it and the back throat

[1] Porter, Sarah Harvey. *Musical Vibrations for the Deaf*, N. Y., 1912, p. 24.

[2] Kempelen, Wolfgang. *Mechanismus der menschlichen Sprache* (Wien, 1791), p. 201 and p. 401. Translation by the author. "A ist der erste Grundbuchstab in allen Sprachen. Alle Kinder sprechen ihn am ersten aus, weil er der leichteste ist. Die Lage aller zur Sprache gehörigen Werkzeuge ist die natürlichste, ungezungenste und bequemste. . . . Dieser Laut kann von jederman, der keine Zunge, keine Zähne und keine Lippen hätte volkommen gut hervorgebracht werden. Darum wird er auch durch Instrumente leicht nachgeahmt. Eine jede Pfeife gross oder klein, die ich nur immer aussprechen liess gab immer ein *a*, nur dass es nach Verhältniss der Pfeifengrösse in einem bald höheren bald tieferen musikalischen Tone lautete, aber beständig ein *a* blieb."

wall. This seems to be the only physiological requirement for its production; and stands as a surprising confirmation of Kempelen's early statement — almost any kind of a front tongue position can be taken and an *a* ("ah") can still be produced. It also indicates the substantial correctness of his conclusion — much the same view was later advanced by Marichelle, one of France's famous teachers in this field [3] — that an individual with no tongue, teeth, or lips, could produce an *a* ("ah"). Therefore, when a deaf child opens his mouth wide and does not give utterance to the vocal sound we should normally expect — a perfectly good *a* ("ah") as in "calm," or ə (uh) as in "the" or "cut" — these X-ray pictures should indicate the correction and how the teacher should make it.

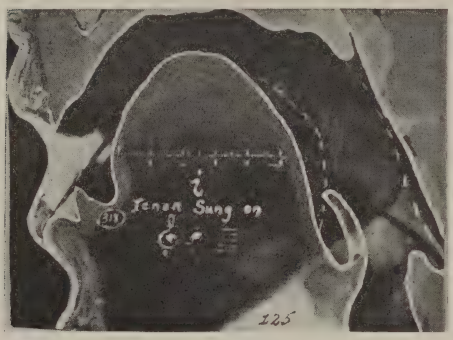


FIG. 72

Position for *a* ("ah"). To secure the best results — although this is not necessary — the pupil's jaws should be wide open and the tongue flat in the mouth, so as to provide the voice tone with a kind of megaphone or flaring horn. Too much attention need not be paid to the front of the mouth, other than to the lips, which may deaden the vowel. Most other defects will be caused by either too large or too small an opening in the low back part of the throat. (Study Figs. 56, 57, 66, 83, 84, 85, 86, 98, 103, 111, 136; and compare 123 with 124; 144 with 149; and 166 with 167.)

FIG. 73

Guttural Vowels. If the vowel he produces is guttural, he is failing to open up the throat passage as he should. This refers, of course, particularly to an upward and backward pinching in of the soft-

[3] Marichelle. *La parole d'après le tracé du phonographe*, Paris, 1897, p. 27.

surfaced cavity in the throat between the tongue, velum, and the muscular side walls formed by the glosso- and pharyngo-palatine arches — especially the latter two and also to the upper glottal (false cord) and laryngeal exits.

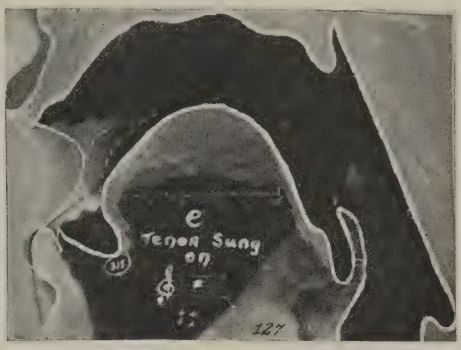


Fig. 74

ɔː (" aw ") in " bawl "

If the vowel is clear, that is, not guttural but rather darker in color, approaching the ɔː (" aw ") in " *bawl*," much the same pinching process of the throat is taking place without being carried to such an extreme in closure as to set the surfaces and saliva into vibration; or else the vowel is being deadened by the lips through the pulling in of the corners of the mouth and the narrowing of the soft-surfaced opening at that exit. Of course both of these factors may be involved. (Study Figs. 55, 67, 75, 88, 112, 125, and 126.)

Fig. 75

æ (" -a- ") in " cat "

Metallic Vowels. If, as is less likely, the vowel is more metallic in quality, the tongue is being humped forward towards the hard palate and teeth; and what is more important, the cavity of the back throat is being opened, especially in the neighborhood of the two aforementioned palatine arches which otherwise would tend to veil the sound when an opening is narrowed at that point — a perfectly natural result since these throat surfaces are extremely soft and flabby. The so-called short *a*h which we write æ ("-a-") in " *cat* " is in all probability the one which will

then most often occur; for it classifies with the front series of vowels treated below, having a bright, ringing, or sometimes snarling or "quack-like" quality, rather than the mellow, or even dull, or dead quality which characterizes the vowels from *a* ("ah") in "*car*" to *u* ("o^{1}o") in "*fool.*"

Fig. 76

X-Ray Contradicts Bell. It will be noted that the tongue position for this vowel is exactly the opposite of what Bell described it to be. For he spoke of the æ ("-a-") as being due to [4]

> "the enlargement of the formative aperture caused by the *depression of the middle of the tongue backwards.*"

The X-ray shows the middle of the tongue, however, to be usually anything but depressed. On the contrary, there occurs regularly a kind of camel-hump at this point. And so while, as the author has pointed out elsewhere, most of these vowels can be produced with quite a wide variety of tongue positions, and the glottal function appears to compensate regularly for tongue position (if not actually to create certain distinctions in vowel quality which we have heretofore been seeking in the tongue position itself); yet these X-rays would seem to justify the conclusion that this

> æ ("-a-") is normally characterized by a decided *hump in the middle of the tongue,* which would tend to *direct the sound forwards* against the teeth and hard palate, thus accentuating the metallic quality.

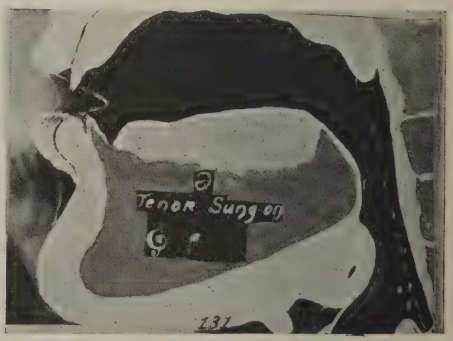


Fig. 77

Now of course this metallic quality is most noticeable when the voice is high pitched; and since a tense, extremely high-pitched voice

[4] Italics mine.

is very apparent in so many of the deaf, it follows that their vowel *a* (" ah ") as in " *palm* " may readily turn into a vowel æ (" -a- ") as in " *pat.*" It is also evident that as girls naturally have higher pitched voices than boys, even at a relatively early age, this vowel would be most likely to occur among them. And since the pitch of the voice seems to be a factor here, a teacher of the deaf may well make use of this fact, where the child has any capacity whatever for pitch modulation. (Study, Figs. 95, 110, 122, and 135.)

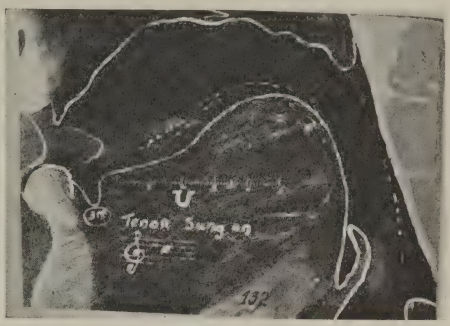


FIG. 78

ə (" -u- ") in " cut " and " the "

This vowel which we know in such words as " *cut,*" " *butter,*" " *some,*" or " *idea,*" " *the,*" etc., is probably the one most closely allied to the *a* (" ah ") in " *father* " [at least after the ɔː (" aw ") and æ (" -a- ") above considered]. It would not be surprising, therefore, to hear a deaf child produce this vowel more spontaneously than it does any other open-mouthed, expiratory, voiced sound. It is unfortunate that so little attention has been paid to its cultivation, at least in courses instructing the deaf in the United States; for it is far and away the most common of all the vowels pronounced in the English of average people throughout the country at the present time, and the deaf child should be trained in a pronunciation which is as nearly normal as it is possible to produce. By so doing we " make him one with the

FIG. 79

people at large " and if he actually speaks as they do, nobody will have occasion to laugh at him and discourage his use of oral speech.

The Dominant English Vowel. It will be noted that we have not distinguished here between the accented vowel in " *but*," " *come*," " *hum*," " *put*," " *foot*," etc., and the unaccented ə in " idéa," " díagrám," " *u*nconvén*tion*ally," etc. If we write this vowel with an ə in both cases, that is, in accordance with the pronunciation the author most commonly hears over the country, the frequency with which it occurs in English will be made evident by counting the number of times it is used in almost any selection we may choose at random. Let us take one from Krapp:[5]

FIG. 80

" The North Wind and the Sun were disputing which was the stronger,
ə ′ ′ ə(æ) ə ′ə ′ə ə(ɪ)′ ′ ə ə ′ ə
when a traveller came along wrapped in a warm cloak. They agreed
′ ə ′ ə ə ′ ə ′ ′ ə(ɪ) ə ′ ′ ′ ə ′
that the one who first made the traveller take off his cloak should be
′ ə ′ə ′ ′ə ′ ə ′ ə ə ′ ′ ′ ′ ′ə ′
considered stronger."
ə ′ ə ′ ə

The vowels used in this passage number: ə, 25; ɪ, 6; ɔɪ, 6; æ, 4; e, 4; i, 2; o, 2; u, 2; ju, 1. The vowel *i* (ee) in " *eat* " is about the only one in our system which is withstanding very successfully the leveling influence operating in that phonetic law now forcing us to substitute an ə (" -u- ") as in " *the* " for any of our other vowels when they occur in unaccented syllables. The ɪ (" -i- ") is gaining somewhat, also, since it is in a like manner being substituted for the unaccented *i* (" ee "). So certainly the deaf should be taught to cultivate the insertion of these two vowels in their proper places, as by such means their speech becomes less conspicuously " different."

[5] Krapp, George Philip. *The Pronunciation of Standard English in America*, Oxford University Press, N. Y., 1919, p. 210.

Physiological Cause of Its Overwhelming Frequency. There are some apparent facts which explain the frequent use of this ə (" -u- "). In the first place since it occurs in unaccented syllables the energy behind it, that is, the energy forcing the vocal cord vibrations, is at a minimum; and this condition is not favorable to its high partials, or to a metallic quality. It also leads to a diminishing of its loudness and consequent clear-cut identity — probably one reason why any indistinct vowel is easily mistaken for an ə (" -u-") "*uh.*" Such a location, in the third place, leads to a reduction of its quantity, or the length of time which the vowel is held, to the absolute minimum. And all vowels need an appreciable length of time in which to develop their characteristic sound patterns.[6] This may be another reason why a vowel held a very short time, and hence one which is not very distinct, is so easily mistaken to be an ə (" -u- "). Then fourth, the unaccented position is one in which the voice pitch falls. And in English, at least, this fall is so radical that the glottal lip vibration degenerates into what is almost a growl (in the author's voice very regularly to 64 double vibrations per second or the second octave below middle c′ on the piano). Under such a stimulus no vowel can be heard distinctly. Furthermore, on such low pitches, the author[7] has observed, fifth, that the soft surfaces of the false vocal cords close over the true vocal cords as an effective damper, with but a pin-head size opening between, through which the

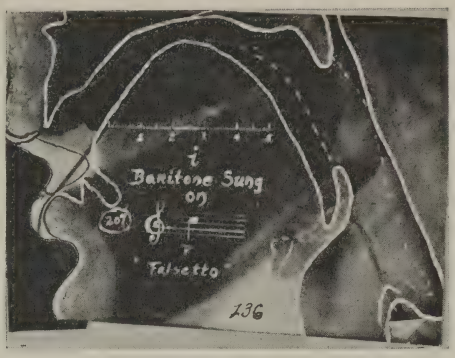


FIG. 81

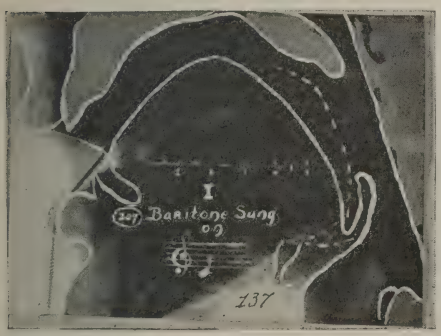


FIG. 82

[6] See "curves" in Crandall, I. B., *Sounds of Speech*, N. Y., 1925.

[7] Through his laryngo-periskop which permits of glottal observation without going over the tongue, depressing it, or in any way impeding its normal movement.

glottal vibration can escape. The inevitable result, as he has elsewhere indicated, is a radical suppression or deadening of at least the high partials. On the other hand, sixth, the tongue position, in which

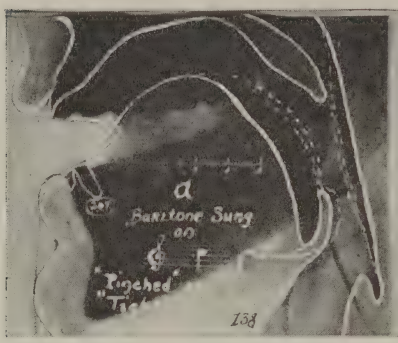


FIG. 83

FIG. 84

it classifies with the back vowels, may show a pharyngeal cavity that is relatively well opened throughout its whole extent from the larynx to the buccal cavity. As a matter of fact it seems to show this spread without a necessary constriction at a given point, differing from: *a* ("ah") which contracts at the epiglottis; ɔ: ("aw") which constricts at the pharynx; *o* ("o-e") which narrows some place between the pharynx wall and the velum; and *u* ("o^{1}o") which usually presents a

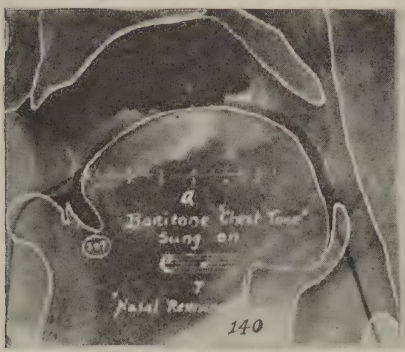


FIG. 85

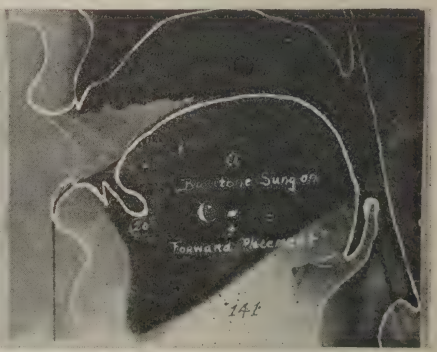


FIG. 86

decidedly narrow channel between the tongue and the velum, with an unusually large pharyngeal cavity below it just above the larynx at the epiglottis.

Finally, if the tongue takes a very flat position at the back, in the production of an *a* (" ah ") (as in Fig. 111, rather than Fig. 137) a mere pulling in of the corners of the mouth, with its consequent narrowing of the exit between the soft surfaces of the lips, will be almost certain to change the *a* (" ah ") to an ə (" -u- "). But if at the start the quality of the *a* (" ah ") — due to a tongue arching higher up, that is, to a constriction between it and the pharyngo-palatine arch — is dead, such a pulling in of the corners of the mouth will change the dead *a* (" ah ") to an ɔɪ (" aw "); and any form of lip manipulation will not be successful in creating an ə (" -u- ") intermediate between the two.

Fig. 87

Fig. 88

These complex factors which may enter into its production — the one compensating for the other under various circumstances to produce practically the same impression — coupled with the fact last mentioned which showed that this vowel might not fall into a normal progressive series, was probably what led to the classifying of it as the " indefinite vowel ə." Yet normally its production may be almost spontaneous and quite as mechanical as the *a* (" ah "). So the author feels that this ə̄ (" -u- ") " uh " should be a relatively easy vowel to teach a deaf child. For ə (" -u- ") study Figs. 53, 68, 77, 87, 113, 127, 139.

u (" o^{1}o ") as in " fool "

This vowel as we know it in " *pool* " and " Sue," etc., should be quite as easy to teach to the deaf child as any of the others we have discussed.

In teaching this vowel it has been customary to work with the child's lips, and the author would not recommend any change. By puckering enough and almost closing the lip opening one is almost certain to change practically any vowel with any tongue position into something approximating an *u* (" o^1o "). This fact was known at least as far back, and probably much farther back, than the days of Pedro Ponce de Leon[8] (prior to 1584).

But the teacher may be confronted with difficulties. One of these will be encountered when with the greatest puckering, the vowel remains essentially an ə (" -u- ") or at best an *ʊ* (" o^2o ") ; in other words when the vowel remains rather " hard " or even metallic in quality, rather

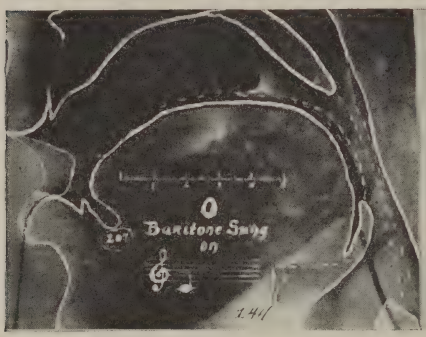


Fig. 89

Fig. 90

than " hollow " or " barrel-like " or dull. This means, of course, that the soft surfaces in the back of the throat are not being brought properly into play, as some kind of narrowing there is essential for fullest quality. Actually, as will be noted, there is usually a decided cavity created below this point, both by lowering the larynx and pulling it forward. The deaf child might probably be made to feel the shift of the larynx by placing his fingers above the teacher's " Adam's apple " ; or a tension with his thumb under the teacher's chin when he is passing from (ah) to (o^1o) with a minimum of lip rounding. In the event of a false *u* (" o^1o ") the teacher will probably find it best to start from an ɔː (" aw ") or o (" -o- ", oh) if the child can produce either vowel. Then while that vowel is being pronounced the teacher can pucker the child's lips with her own hands. Of course we must not lose sight of the fact that a large part of this bad *u* (" o^1o ") quality probably comes from the lack of a

[8] Spanish monk, and noted father of work in training the deaf to speak.

big barrel-like throat resonator, or from a wide open throat and front mouth tube. (The tongue positions for this vowel are to be found in Figs. 52, 70, 80, 91, 100, 105, 116, 130, and 171; the tongue shifts made in passing to and away from it — in other words the diphthongs of which it forms a part — in Figs. 142, 143, 145, 146, 148, 150, 151, 152, 153, 154.)

o (" o-e ") as in " tone "

Once the extremes, as represented by *a* (" ah ") in " calm " and *u* (" o^{1}o ") in " Sue " or " boot," are obtained, it should be a relatively easy matter to teach this vowel. In every sense of the word, it represents

Fig. 91

Fig. 92

an intermediate stage between the ɔ: (" aw ") and the *u* (" o^{1}o "), and it requires nothing more than a lip opening intermediate between these two. Kempelen obtained it mechanically by sliding a board halfway across the mouth of his *a* (ah) horn. Of course it can be obtained with the lips wide open, merely by shifting the position of the tongue so as to narrow the velar aperture and make a bottle or resonator of the lower throat. But this is a more complex process. The deaf child who is dependent on lip reading should, however, be made aware of the fact that this is regularly done in normal speech, and that no puckering then occurs. (Study the position for this vowel in Figs. 54, 69, 79, 89, 90, 99, 104, 115, 128, and 170; and the diphthongs, or tongue shifts made in passing to and away from it in 142, 147, 148, 152, 153.)

ʊ (" o²o ") in " foot "

This vowel represents the intermediate stage between ə (" -u- ") and *u* (" o¹o "), and corresponds to the relationship of *o* (" o-e ") to ɔ: (" aw ") and *u* (" o¹o "). Once the student has learned to sound ə (" -u- ") as in

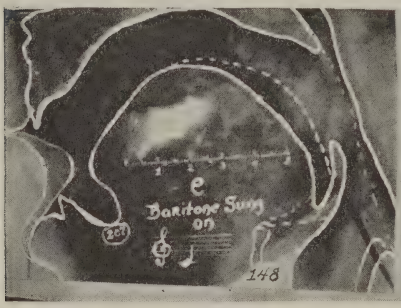


Fig. 93

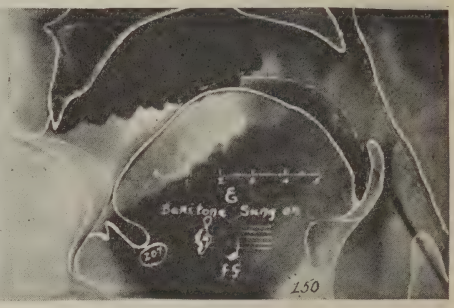


Fig. 94

" *bunt* " or " *vocal* " a slight rounding of the lips should give a very good *ʊ* (" o²o "). The close relationship between these three vowels is evident in the current pronunciations of the word " *soot* " which may be heard as " *sut*, *sʊt*, or *sət* " (" so¹ot, so²ot, s-u-t "). It will be noted that the transition is not through either the *o* (" o-e ") as in " *tone* " or the ɔ: (" aw ") as in " *bawl.*" (For vocal positions study Figs. 71, 92, 114, 129.)

With this group of vowels we have covered those that constitute the majority used in the English language. We have found that practically all of them can be reproduced, though somewhat imperfectly, by mechanical means and that they will probably give little trouble in the teaching of the deaf. As the author[9] has already pointed out in his study " Visualizing Speech for the Deaf," reported before the convention of American Instructors of the Deaf, the greatest

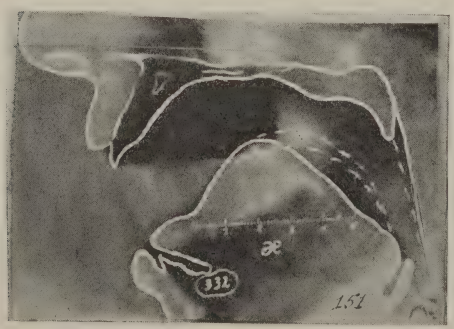


Fig. 95

[9] By the author. "Visualizing Speech for the Deaf," *American Annals of the Deaf*, LXXII, No. 4, pp. 329–340.

difficulties for the teacher lie in the teaching of the balance, most of which are front vowels. To these we may now turn our attention, beginning again with the most extreme. It is also the most difficult vowel to teach.

i (" ee ") in " peep "

Heretofore we have conceived of this vowel as arching against the front teeth and alveolar ridge. The X-ray shows it, however, as actually arching as far back as the soft palate where contact takes place for the *k*.[10] This position creates a long narrow cavity, usually not as large as the index finger and of about that length, pinched in against the hard sounding board formed by the bony surfaces and the teeth which make up the roof of the mouth.

A front arching is not the only requirement made of the pupil who would reproduce this vowel. The back throat cavity, apparently in order to eliminate effectively the deadening influence of the soft surfaces, has to be spread open as wide as possible. Then too, but a relatively short shift backwards, covering a movement of not more than an inch with the cavity dimensions remaining otherwise essentially the same — but thereby bringing the narrowest constriction against the soft palate instead of the hard — will cause the *i* to change to an *u*. This appears from a comparison of Figs. 62 and 70 or of Figs. 106 and 116, though in the latter case the back cavity is very much smaller for the *u* (" o¹o ").

The author hopes that these X-rays may lead to better results than have heretofore been possible in the teaching of this vowel to the deaf. At least they show many facts which were not heretofore suspected. The point of arching and the vital importance of the back-throat cavity in the production of this vowel are two of them.

It has been customary to use point-lingual fricative consonants as a starting point in the teaching of this vowel, and this must still be considered a wise policy. Possibly the *z* is the best of these with which to start, since it sets up surface vibrations which are very nearly akin to the quality in the *i* (" ee "). If while the student is sounding *z* the tip of

[10] So the words " key," " keep," etc., could well be coupled with such as " see," " tee," " she," in teaching the *i* (" ee ").

his tongue is barely pressed down with a pencil, the vowel which results can often be distinctly heard. It may show as an *ɪ* (" -i- "), often as an ɛ (" -e- "), more often still as an ə (" -u- "), and sometimes even as an

FIG. 96

FIG. 97

u (" o^{1}o "), etc. When this happens the lips should be examined first to see that they are spread wide and out of the way in a smiling position. The real cause of failure, however, lies in the fact that the tongue is closing up the throat cavity and causing the sound to be deadened by the soft surfaces at that point. And it is this tendency which must be overcome. In extreme cases where it does not gag the child too much the teacher's finger may be used to keep the throat open. (In this case the teacher should remember that the gagging is most likely to result when the soft palate is touched, making it necessary to slide the finger along the surface of the tongue.) By such means it may be possible to pull (down in the region of the epiglottis) the back part of the tongue forward. This gives the throat cavity a distension that is absolutely necessary, and at the same time shows the child that the whole front tongue cavity all the way back to the end of the hard palate should be no larger than the finger and about as long.

FIG. 98

But there is still another condition, over which we can exercise but

little direction, necessary for the production of this sound. The vocal cords must be free to vibrate with the least possible amount of damping. This damping effect seems to come mostly from the cushion of the epiglottis, and possibly as well from the soft surfaces of the false cords;[11] and for this reason the epiglottis must be kept well open and forward if this vowel is to be produced clearly. The muscle which opens the back cavity and pulls the epiglottis forward attaches to the chin and the pupil can usually be made to feel its tension by pressing his thumb tightly under the teacher's chin while the latter says "*ah-ee-ah-ee*" (*a-i-*). Since an unstrained high pitch brings about an analogous result, this

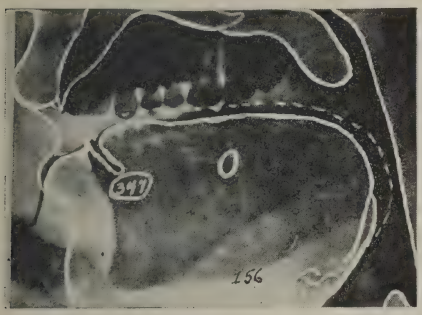


FIG. 99

FIG. 100

fact may be utilized where the student has any pitch control. In other words in order to put the vocal cords in the proper position, he can well be encouraged to produce his *i* ("ee") on a moderately high pitch (by moderately high pitch is not meant the squeak so many deaf have) rather than on the low-pitched glottal note used for back vowels. (Study 58, 62, 72, 81, 96, 101, 106, 117, 162; and the diphthongs or shifts up to and away from this vowel, in 144, 146, 147, 149, 154, 155. See the vocal cord position in Fig. 17. Compare Figs. 18, 14.)

The other vowels in the front series are so much more simple than the *i* ("ee") that it would be surprising indeed if the deaf child did not automatically bring forth practically all of them in the course of his attempts to produce this one. And of course the wise teacher will utilize this fact. The author agrees heartily with Bell in the wisdom of telling

[11] This fact appears from observations made with the author's laryngo-periskop.

a child what he does produce rather than of merely shaking the head and telling him that it is wrong.

ɪ ("-i-") in "*pit*"

It is the exceptional deaf child who does not actually pronounce this vowel for the *i* ("ee") he should be using; at least this seems to be true except where the latter vowel is given on a high pitch. This *ɪ* ("-i-")

FIG. 101

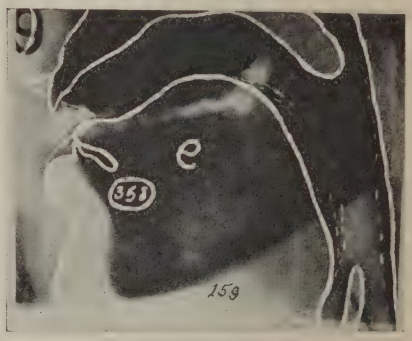


FIG. 102

as in "*tip*" seems to be what might be termed the "dull" counterpart of the *i* ("ee") as in "*team.*"

If the child has actually succeeded in learning the *i* ("ee") the teacher need only take a pencil and press the fore part of the tongue down a bit, in order to turn that vowel into an *ɪ* ("-i-"). Otherwise very much the same devices can be utilized as were recommended for the teaching of the *i* ("ee").

So far as the tongue position is concerned, a comparison of Figs. 62 with 63, and 131 with 132, or 117 with 118, or 106 with 107, would seem to indicate two primary differences between these two vowels. The first is that above indicated, the front cavity for the *ɪ* ("-i-") as in "*pip*" is usually considerably larger than that for the *i* ("ee") as in "*peep.*" The second difference concerns the back cavity, which is usually smaller for the *ɪ* ("-i-") than for the *i* ("ee"). The cavity tones resultant here, however, would seem to be less important than the "deadening" effect

on the " tonal quality " of the vowel which those surface influences accomplish; at least the fact that the back cavity for *ɪ* (" -i- ") constricts mostly at the bottom, thus narrowing the laryngeal exit, would seem so to indicate. Because this manifestation is more constant and characteristic than either of the others mentioned.

On the other hand, there can be little doubt but that much of the difference in quality may be accomplished in the function of the vocal cords. This is where the " brilliant," or " ringing," or " metallic " quality in

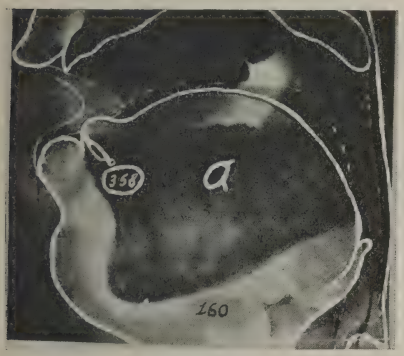


FIG. 103

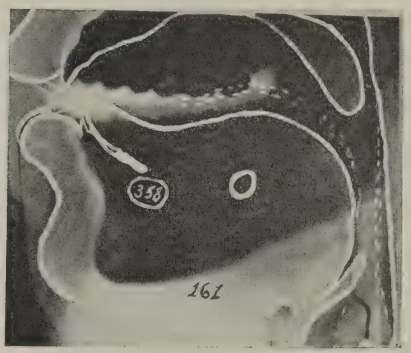


FIG. 104

the *i* (" ee ") has its original inception; and the damping function of the cushion of the epiglottis and possibly that of the false cords may be the one really involved.

(Study Figs. 63, 73, 82, 107, 118, 132. Compare Figs. 16 and 17.)

e (" a-e ") in " cake "

This *e* (" a-e ") as in " *pate* " has like the *i* (" ee ") as in " *peat* " a very characteristic " metallic," or " brilliant," or " ringing " quality. This is particularly noticeable when it is compared with the *ɪ* (" -i- ") as in " *pit* " or the ɛ (" -e- ") as in " *pet.*" It is striking to note that the latter two may take relatively flat front tongue positions in comparison with the high-arching and humped-up-rounding position of the tongue against the hard palate found for both *e* (" a-e ") and *i* (" ee "). Then

too, the astounding similarity of the epiglottal position taken for these two — spread wide with a peculiarly constricted hump tending to close the laryngeal opening — cannot be without significance where the resemblance is as pronounced as between the pairs in Figs. 106 and 108 when compared with Figs. 107 and 109. There would seem to be justification, therefore, for considering *ɪ* ("-i-") and ɛ ("-e-") as the "dull" counterparts of *i* ("ee") and *e* ("a-e"). Fig. 110 seems to show that *æ* ("-a-") leans toward the latter two in its forward hump, but follows the tendency of the first two in so far as its epiglottal position is concerned.

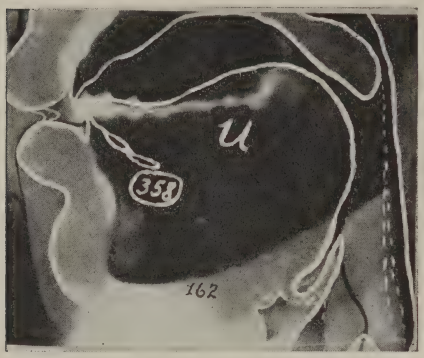


Fig. 105

On the other hand, when the two are whispered, we have difficulty in distinguishing between the pure prolonged *e* ("a-e") and the prolonged *ɪ* ("-i-"). So aside from the quality the vocal cords give them, these two must have much in common. For this reason the teacher could well work with the one while struggling with the other.

Finally, it may be suggested that if the child succeeds in getting a good *i* ("ee") the teacher can do much towards helping the production of the

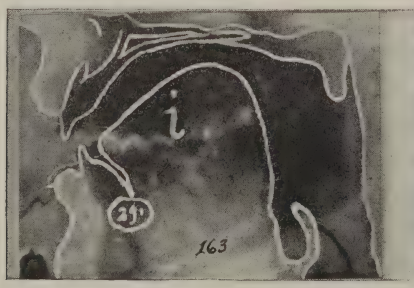


Fig. 106

Fig. 107

e ("a-e") by calling for the *i* ("ee") position and then pressing the tongue down rather forcibly with a pencil or spatula placed between one and two inches back from the teeth. (Study Figs. 60, 64, 74, 93, 97, 102, 108, 119, 133, 164, 143, 145, 150, 151, 155.)

ɛ (" -e- ") in " pet "

This ɛ (" -e- ") as in " *pep* " is not far removed from the æ (" -a- ") as in " map " ; and from what has been said above, it will be evident that

FIG. 108

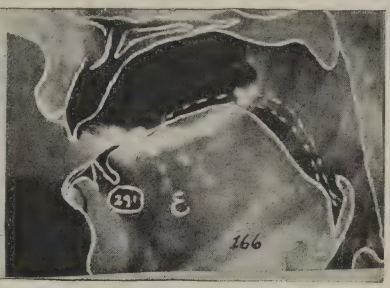


FIG. 109

it will give the least trouble of all the front vowels. If it is too " dead," however, it may turn into an ə (" -u- "). Then the teacher's task is primarily one of teaching modulation. (Study Figs. 61, 65, 94, 109, 120, 134, 165.)

CHAPTER XV

THE SINGING AND SPEAKING VOICE

"Many singers try their whole lives long . . . and never succeed. This happens because science understands too little of singing, the singer too little of science. I mean that *the physiological* explanations of the highly complicated *processes of singing* are *not plainly enough put for the singer*, who must depend on his vocal sensations. Scientific men are not at all agreed as to the exact functions of the several organs, and the fewest singers are informed on the subject. Every serious artist has a sincere desire to help others reach the goal — the goal toward which all singers are striving: to sing well and beautifully."

— Lilli Lehmann.[1]

Speech X-Rays Valuable to Voice Teachers and Students. It would seem that the X-rays given herein would be of value to all voice teachers and their pupils — if for no other reason than that they show the posi-

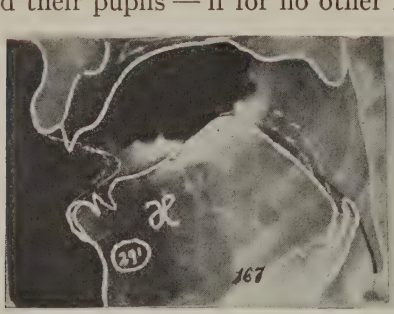


Fig. 110

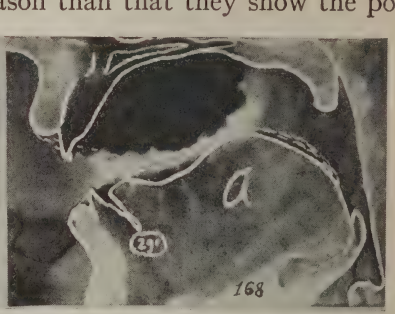


Fig. 111

tion of the tongue and other vocal organs as they occur in normal everyday speech. Certainly all could make good use of this knowledge, if only in order to avoid the mistaken positions which no one who desired to become an artist would like to cultivate. The value of this visual information should be all the greater in view of our inability to feel what these positions are, any more than we can sense our heart beat or our digestive functions. At any rate the author has hoped that they might be of interest to the profession and is gratified at the reception their first presentation has received.

[1] Lehmann, Lilli. *How to Sing*, Macmillan Co., N. Y., 1924.

No Theory to Advance. It might be well to reiterate the fact that this study was not undertaken for the purpose of defending any " singing theory." The author has none. The experimental laboratory has no other purpose than to ascertain the facts. In this case the facts we were seeking were the fundamental ones involved in " how we talk " — or in other words those revolving around the numerous conflicting theories which seek to explain *vowel* and *voice quality*, but the reader will note that considerable information which bears directly upon conflicting singing theories may be gleaned therefrom.

Confirmed by Other X-Rays. Both the X-ray experiments reported herein, as well as those of Barth,[2] Scheier,[3] Eijkman,[4] Hoffmann,[5] *et al.*,

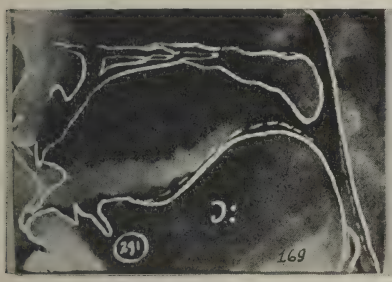


FIG. 112

FIG. 113

would seem to indicate a necessity for the revision of many widely accepted theories held by singers and some of their teachers in regard to tongue position. By this statement or any of the others made in this discussion, the author would not have it appear that he would recommend the tongue positions taken by either the baritone, tenor, or soprano, discussed herein. It may well be that they are all entirely false. No one knows yet. This much may be said, none of them thought they were taking the tongue positions X-rayed. The baritone was so positive that his tongue did not make a narrow pharyngeal opening in the production of " ah " (*a*), that ten different exposures of this vowel had to be made on two different days — and then he went away shaking his head.

[2] Barth, E. and Grunmach, E. "Röntgenographische Beiträge zur Stimmphysiologie." Subject was one of the Berlin opera soloists. Vowels: I, E, A, O, U; Oa, Ae, Ue, Oe. *Arch. f. Laryng. Bd.* 19, Heft 3 (1907), pp. 396–407.

[3] Scheier, M. "Bedeutung des Röntgenverf. f. d. Stimme u. Spr.," *Ibid., Bd.* 22, H. 2 (1909), p. 175.

[4] Eijkman, L. P. H. "Radiographie des Kehlkopfes, Fortschr a. d. G. d. Röntgenstrahlen," *Bd.* VII, Heft 4 and 6 (1904), and *Vox*, June, 1914.

[5] Hoffmann, C. "Stimme," *Vox*, 1916.

(Four of these are given herein, along with the terminology he used to describe the tone: Fig. 83, "pinched or tight-tone," which in the back is exactly the opposite of the position he thought he was taking;

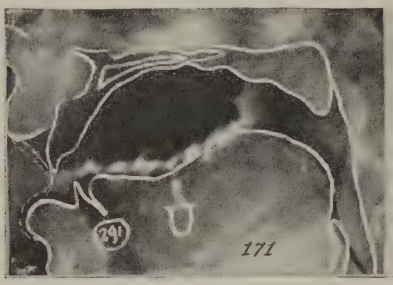


FIG. 114

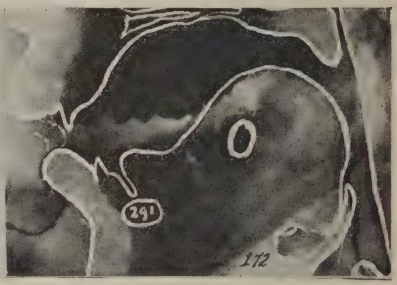


FIG. 115

Fig. 84, "falsetto"; Fig. 85, "chest tone"; Fig. 93, what he called "forward placement.") No doubt many teachers of voice, with theories which do not agree, will oppose any or all of these positions; and their views may be correct. Experiment only can show.

More Experiments Needed. Members of the American Academy of Teachers of Singing have initiated a very extensive investigation the author has agreed to direct along the lines indicated herein (which with present experience can be much improved upon). It is hoped that a large number of singers of international reputation can be utilized; and the final results will make it possible not only to see the positions of the tongue and other vocal organs, but also to listen back to the tonal quality as it was produced. This will of course give much more conclusive and useful evidence than that provided herein. In the first place everybody will be able to compare the result heard with an X-ray of the tongue position which gave it. Of course even this does not mean a unanimous agreement on what is to be accepted or cultivated and what is to be rejected. No doubt there will still exist widely divergent opinions even as to whether the quality of a voice is what it should be. Human nature is so constituted that each one will inevitably have his pet theories and

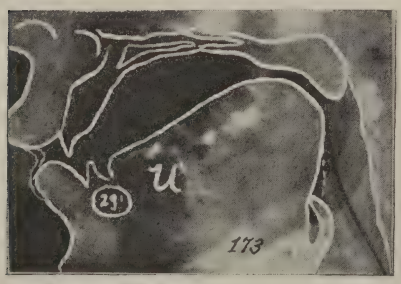


FIG. 116

base his judgment very largely on what conforms to or fails to agree with them. So, for example, one may say that a wide divergence of opinion can be expected, even where agreement is sought, on the various

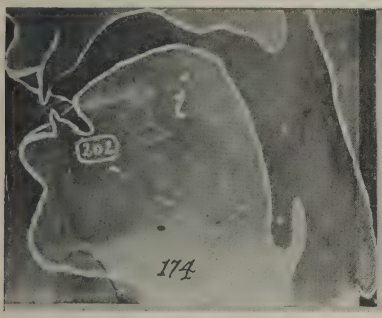


FIG. 117

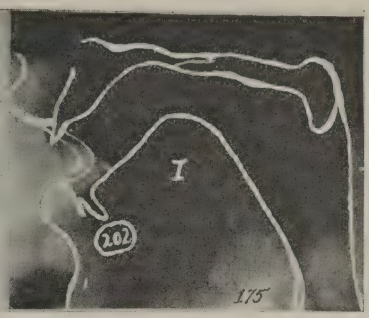


FIG. 118

aspects of quality in Caruso's voice or on that of any other widely acclaimed singer.

In the meantime, however, the author may be justified in disregarding such disagreements and in calling attention to some of the facts shown in the present series of experiments which both the voice teacher and student will probably be glad to note.

Spoken Vowels. If we limit our first consideration to some of the positions which are taken in untrained speech, there will probably be

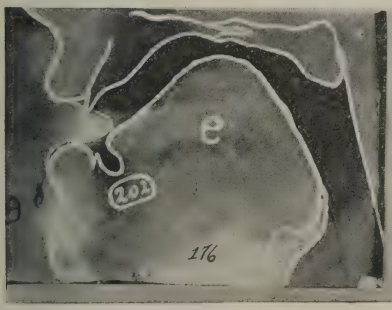


FIG. 119

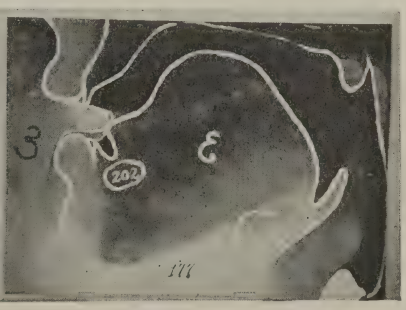


FIG. 120

less occasion for us to disagree; and all voice teachers or students will undoubtedly see some value in their work. Indeed many outstanding authorities in the field, such as Professor Percy Rector Stephens, have

even maintained that there should be no difference between the spoken and sung vowel. However, even a more potent reason for starting at this point can be given. Many very famous voice teachers appear to have held opinions (in regard to what the tongue is doing in ordinary

FIG. 121

FIG. 122

talking) which are quite at variance with the positions shown in the actual X-ray photographs.

X-Ray Gives Heretofore Unknown Facts. The author hopes that the reader will not take this as a condemnation. It is not so meant; for the facts were heretofore not available. Hence the teacher, and the writer of various treatises on how to sing, was of necessity forced to rely on the only thing left — that is to say, he was forced to construct an imaginary position for the tongue dependent for the most part on what his sensation seemed to indicate; and at least in the case of the vowel " ah " (*a*), to a less extent upon what he could see with the naked eye. The latter statement in regard to the eye is made advisedly, for what can be seen

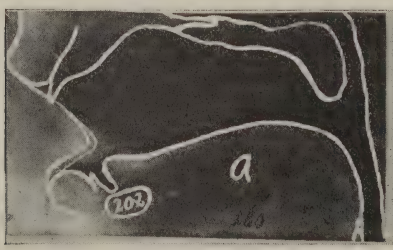


FIG. 123

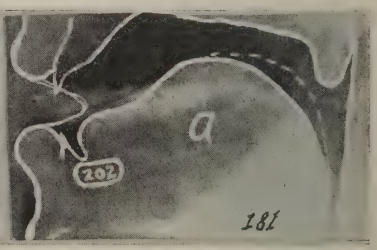


FIG. 124

from the front, through a relatively small opening, gives of necessity but a very limited and sometimes a distorted idea. This will be evident to one who makes a comparison of the various *a* (" ah ") and *æ* (" pat ") positions, shown in the figures cited below.

Examples of Erroneous Ideas. Let us take, to begin with, a quotation which appears to be quite typical. It comes from a publication on learning to sing which probably has had as wide an international sale as any thus far to appear :

> " The ordinary ' ah ' (*a*) as practically pronounced by every layman, and so often demanded by many teachers of their pupils, is an absurdity, as the tongue is usually pressed down — not only by false habit but often pressed down artificially with instruments. This leads to *flat*, ordinary, defective singing, if not often to the ruin of the voice itself."

This quotation evidently refers to speech. The idea advanced is an old one — viz., that in speech the position of the tongue for " ah " (*a*) is flat in the bottom of the mouth. And this singer has added to his view by ascribing a " flat " quality to this position.

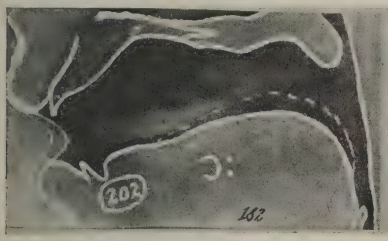


FIG. 125

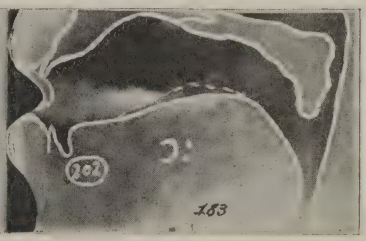


FIG. 126

Error Analyzed. As a matter of fact we will see that this vowel may, and commonly does, even in the same speaker, take almost any buccal position and still remains a perfectly normal " ah " (*a*). The reader will note this fact in an examination and comparison of Figs. 123 and 124. Both are X-rays of the vowel " ah " (*a*) as made by the same speaker, and that within a few minutes of each other. And since we can listen back to the speech record made simultaneously with the X-ray, there can be no question as to the facts involved. The " ah " (*a*) in Fig. 124 is anything but " flat." If the author were going to describe the quality, he would say that neither it nor that in Fig. 123 are heard with a quality anywhere near as " flat " or " metallic " or " voix blanche " (if those terms mean the same thing) as is that heard in the record for Fig. 98.

Throat Closes. The only characteristic which really seems at all typical of the physiological position of the cavity taken in order to produce this vowel, whether sung or spoken, would seem to be manifest in

the relatively closed epiglottal aperture which is invariably assumed. (See Figs. 66, 75, 83–86, etc.)

Where Quality Was Analyzed. This brings us to the question of quality as it seems to be brought about by our physiological mechanism.

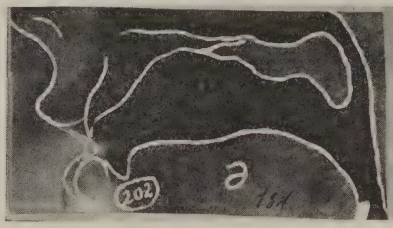


FIG. 127

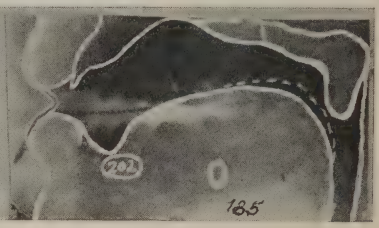


FIG. 128

The author has made a more detailed analysis of this question: **first,** in his study of surfaces and their function in altering tonal quality; **second,** in his chapter on front vowels; **third,** in the one on back vowels; and **fourth,** so far as former theories on air volume resonance are concerned, in the chapter on cavities.

Cause of Quality Summarized. His own conclusion drawn from a study of these X-ray and laryngo-periskopik experiments lead him to believe that much of that "tonal quality" which we recognize in the *vowel*, as well as in the *singing* and *speaking voice*, may be sought:

FIG. 129

FIG. 130

1. In the function of the interior larynx mechanism.
2. In the modification of those quality-producing partials and accompanying tones, brought about by the surfaces above (as they are varied in tension, aperture constriction, and amount exposed).
3. In surface noises added.
4. In a sounding-board function bringing about a loudness which is so often falsely called "resonance."

5. In soft-surface deadening, or the opposite of the loudness mentioned in 4.
6. In the sometimes megaphone-like amplification or concentration of the sound which also makes for loudness just as does the sounding-board listed in 4.
7. In the accentuation of one or two given overtones or their bands or the addition of the " formant " if you will, brought about by the total volume of air in the cavity.

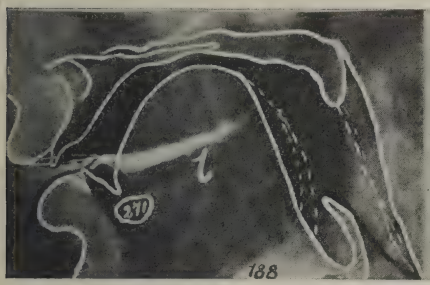


FIG. 131

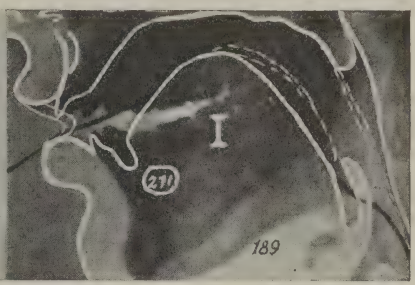


FIG. 132

Terms " Resonator " and " Resonant " Confused. Among scientists the tendency has been to devote practically all attention to the factor listed in 7; and their usage of the term " resonator " in reference to the same, has by singers been too often confused with what the latter designated as " resonant." This has of course led to many misconceptions and considerable confusion. It may be illustrated by a typical quotation from an author on singing:

> " Take an ordinary tumbler and partially cover its mouth with a thin book. . . . When the right-sized opening is found, the sound of a tuning-fork " (held in front of it) " will be largely reinforced. In a like manner, in singing, the small initial sound produced by the vibrating element of the voice-organs is reinforced by vibrations communicated to the air contained in the resonance-chambers."

It will be noted here, however, that the tumbler with a given amount of air and a set opening will produce this resonance on and hence respond to the pitch of a tuning fork of only one given note, or to its immediate harmonics. If the mouth functioned as a glass resonator, every time the pitch was changed it would be necessary to change the resonator. So

that if the above statement were true, this would mean that the artist who sang a scale, say on the vowel *a* (" ah "), would have to be constantly shifting his tongue and changing the vocal cavity serving as the " resonator " (that is, making it smaller and smaller the higher the note ascended). Or accompanying this, he would have to spread his lips more and more towards a snarling position as the tone got higher and higher pitched. Is this what the voice teacher would recommend? Is it not apparent that what the singer calls " resonance " is not obtained by any such means? Surely we need not consider this question any further.

Another Error Analyzed. Another quotation bears on a point which is very closely allied to this one :

> " Sing a sonorous *a* (' ah ') . . . with the mouth and nose inserted in a flower-vase, and the vowel sound will be neutralized and the vibration to a great extent suffocated. In a like manner the sound which has been reinforced by the good position of some of the resonance-chambers may be suffocated and spoiled by a bad position of any one of the remaining ones."

The " resonance " would as a matter of fact be just as much suffocated, and the vowel sound be just as much neutralized (if not more so), with a big soft-rubber sponge placed over the mouth and nose as a substitute for the flower vase. What has really happened here is that the sound is penned in and deadened because it has no way to escape except through the sympathetic vibration of the walls. There is no such function here as that involved in one resonance cavity neutralizing the effect of the other. Nor is there likely to be such a condition existent to account for bad singing as opposed to good. This is physiologically impossible.

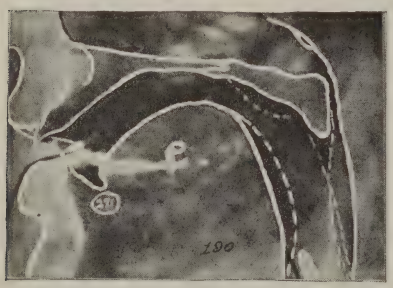


FIG. 133

Why One Cavity Cannot Neutralize the Other. The reason is evident. When we put one cavity in front of another we speak of them as *coupled cavities*. If they are quite unlike in size each will of course retain a pitch of its own which is natural to it in that state. But we need to bear in mind the fact that this pitch is not necessarily what it would be if either were actuated alone. In the chapter on cavities we have summarized

the laws dealing with this altered pitch resulting from " coupling " and quoted Sir Richard Paget who is responsible for their statement. If the pitches of these two cavities are not in tune with each other there results what the physicist calls " forced vibration." Let us quote the law from D. C. Miller : [6]

> " In forced vibration, the two bodies have different natural frequencies, and the resulting common forced frequency is in general not that natural to either body."

It follows, therefore, that one of these cavities will not " neutralize the other," and thus produce a condition which moves in the direction of

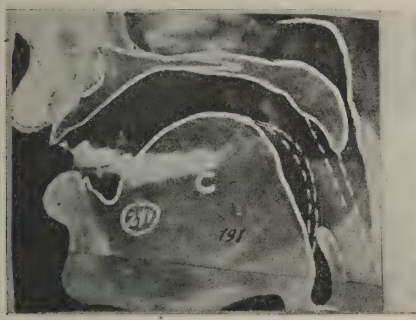


FIG. 134

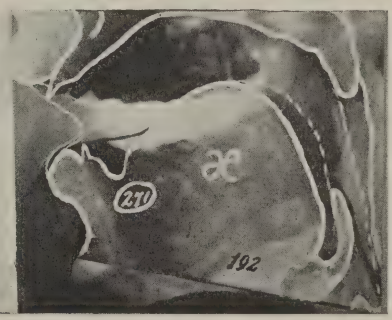


FIG. 135

silence, or reduced loudness, or " suffocation," as the author of the above-mentioned quotation erroneously imagined.

How Tone Is Deadened. On the other hand, there is no denying the fact that the tone is " deadened " by placing the vase or sponge over the mouth. If, instead of a vase, a coffee-pot provided with a spout through which the sound can escape is used, a decided difference in tonal quality will still be noted, and there will be no inconsiderable alteration in so-called " resonance " (or if you will, a lack of pleasing and properly distributed " loudness " in the partials or concomitants of the tone as a whole). If a hole is cut, even as big as a walnut, through the sponge, much the same change will be heard. And if this hole is small enough, the tone then sounds " hollow " or " barrel-like " in quality. By way of explanation, let us quote again from D. C. Miller : [7]

[6] Miller, D. C. *Science Musical Sounds*, 2nd ed., 1922, Macmillan, N. Y., p. 177.
[7] *Ibid.*, p. 179.

"The loudness and the duration of the sound from an instrument are dependent upon the damping or absorption of the vibration in the instrument and its surroundings. The energy of the waves which travel outward from a sounding body is derived from the vibration of the body; usually not all of the energy of vibration is transferred, some being absorbed and transformed into heat through friction and the viscosity of the body. . . . Both the tones generated by a musical instrument and those reproduced, as well as those absorbed or damped, depend in a considerable degree upon the material of which the various parts of the instrument are constructed."

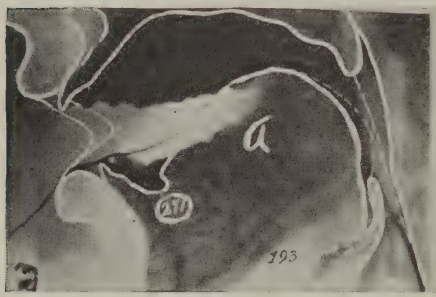


FIG. 136

FIG. 137

Effect of Narrow Soft Channel. For, as the author has pointed out, the forcing of a tone through a narrow channel in soft surfaces tends to do two things:

1. It reduces the "loudness" or "deadens" the tone as a whole, especially where the narrowing is excessive.
2. Its first effect, as you begin to bring such soft surfaces into play, is to "dampen" or "mellow" any piercing, metallic partials in the tone, thus producing what we call a "full," "round," "rich," "mellow" tone; or where narrowed still more and carried to the extreme, leaving but a "dead," "hollow," or where the surfaces themselves vibrate, a "guttural" tone.

So the experiment described by the above-mentioned writer is after all a good one to use in demonstrating one type of "tonal" or so-called "placement" quality. We need but to pass, then, to a consideration of the vocal cavities in order to see how they may accomplish the same result.

An X-Ray of a "Mellow" Tone. A beautifully "soft," "mellow," and yet "resonant" tone was produced by the soprano who sang the

u (" oo ") in " Moon Deer," shown in the X-ray of Fig. 70. It will be noticed that the whole pharyngeal cavity, from the glottis to the velum, is opened wide. It thus stands in quite striking contrast to the ordinary spoken *u* (" oo ") of the young lady who pronounced for Fig. 116, or of

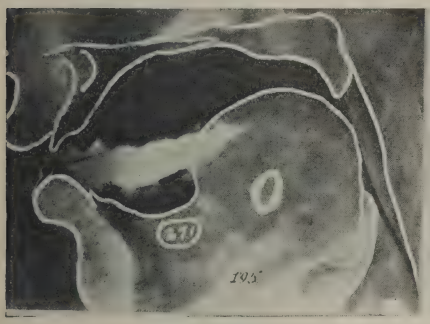


FIG. 138

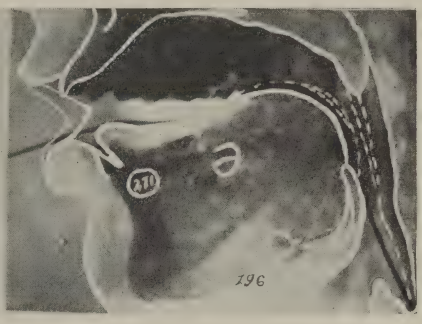


FIG. 139

the one who pronounced for Fig. 141, as well as the German gentleman who pronounced the *u* (" oo ") in " mut " shown in Fig. 171. These latter three are very distinctly " muffled " in comparison with that of the singer.

An X-Ray of a " Metallic " or Even " Strident " Tone. On the other hand Fig. 130 gives the *u* (" oo ") pronounced by a child who had still, at her early age, a distinctly unmodulated and anything but a " soft-

FIG. 140

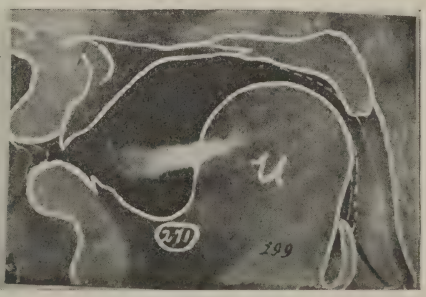


FIG. 141

spoken " voice. Her voice had, rather, a piercing and barbaric quality (as children's voices tend to have before they are successfully softened by training). It will be noticed that the tongue arches well towards the front palate (as does the hard metallic *æ* as in " cat," Fig. 95), and takes

such a position that the sound encounters no constriction between the soft surfaces in the back part of the throat, or otherwise until it reaches the lips.

Reasons Analyzed. As between all these figures, the main differences in the position of the vocal-organs are to be noted in the back of the throat. And that is exactly what a study of these X-ray experiments, and an application of those known principles of physics (which the author has dealt with in his study on surfaces) would lead us to expect:

the longer the gamut is which a tone has to run through a narrowed soft-surfaced channel, the " deader " that tone becomes; whereas a spreading and enlargement of that soft-surfaced cavity tends to minimize that effect.

In this group of X-rays above cited, we have represented for us: the " blatant " or " metallic " or " voix blanche " [8] *u* (" oo ") of the child in Fig. 130; and the other extreme of a " dull " or even " dead " *u* (" oo ") known in normal speech, shown in Figs. 116, 141, and 171; while in between these vicious types so often manifest in uncultured speech lies the soprano's " mellow " and yet " resonant " and far-carrying *u* (" oo ") as caught in Fig. 70.

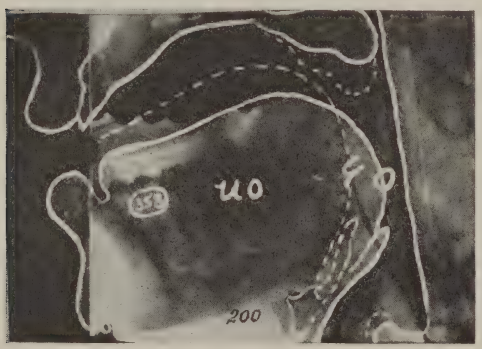


Fig. 142

Correct Tonal Quality. No doubt everybody would be glad to cultivate some such tone as that represented in the latter. To put this idea in the words of Annie W. Patterson:

> " There is an art in controlling the voice so that it will 'carry' to the extreme limits of the apartment, no matter what may be the capacity of the latter. Once this art is acquired, the painful sensation of effort or straining passes from the voice of the singer."

Much of this art must consist in avoiding these two extremes of bad " tonal quality." In any event, while we agree with John Pyke Hullah that:

[8] Def. (Larousse) " les voix de soprano et d'alto sont des voix blanches; la flûte, le hautbois, le violon etc. sont des instruments à voix blanche."

"The first business of him who addresses the public, whether in speech or song, is to be heard;"

yet surely a properly trained adjustment would not call for the admission that

"if the vowel" *e* as in *they* "is more easily heard than" *i* as in *machine* "and the vowel *a* ('*ah*') than *e* we must continue to put up with *say* for see, and *sai* for say."

Use of One Vowel Quality to Illustrate the Same Effect in Another. Such a statement does not quarrel with that commendable practice voice teachers have of utilizing the good quality manifest in the timbre of one vowel to train that same quality in the singing of another. For it is a fact that in normal speech we naturally produce a different characteristic quality in different vowels; and it almost seems as if we could recognize therein the various characteristics (even though somewhat distorted) of most of the timbres, or "tonal," or so-called "placement" qualities known in good singing. This widely used practice would therefore seem to be a wise one when utilized as recommended by Manuel García:

FIG. 143

"Passing from a ringing to a dull vowel on the same note may also be recommended to improve the latter; Ex. *ia, ia, ia, ie, ie, ie, io, io, io*;" . . .

For where attention is directed to this effort, the good qualities of the one may by this means be carried over to the other.

Compensations Common in Speech. One need not be so concerned as on first thought one might be, about thereby distorting speech; for as we string vowels together haphazardly in normal speech so we regularly force one vowel to assume certain aspects of the quality in another. Take Fig. 149 as an example of normal speech (caught by rapid moving-picture X-rays) as it passes quickly from one extreme to the other in uniting two vowels in the Italian language. Here this process would

probably be as pure as can be found, since as Harry Collins Deacon has said :

> " The Italian language is preëminent in its vocal purity. . . . Its vowels are the pure elements of language in general, resembling in idea the painter's palette of pure colors."

X-Ray Proof. Signor Santini has pronounced for us in Fig. 149 the two vowels " *ai* " as a short staccato exclamation on a rising pitch. Here it will be noted that the *i* (" ee ") shows a wide-open front cavity quite unlike most such in speech; yet this is exactly the type of cavity the singer should cultivate on loud and high-pitched notes. In the first place the front cavity assumes more of a megaphone shape, and the vowel in consequence, like the *a* (" ah "), has considerably more " carrying power." In Italian speech the loudness or intensity of the *a* (" ah ") would normally be about four times as great as that of the *i* (" ee "). In the second place, the *i* (" ee ") is by far the most " strident," or, better speaking, " metallic," of the vowels. As the author pointed out in his study on front vowels, though this quality may well originate in the vocal cords as would appear from a comparison of the *i* (" ee ") in Fig. 17 with the ɛ (" pet ") in Fig. 14 (the latter might indicate a considerable deadening owing to the soft surface of the cushion of the epiglottis creeping backward over the vocal cords); yet this metallic quality might easily be accentuated where the front cavity is constricted against the sounding board provided by the bony palate and teeth, especially when the lips are out of the way so as not to exercise their deadening function as soft surfaces.

FIG. 144

Voix Blanche. It would appear to be this hard-surfaced constriction, or even the sloping of the back part of the tongue forwards toward this hard-surfaced area — as in our normal, spoken, snarl-like æ (of " cat ") [study Figs. 95, 110, 122, and 135] — coupled perhaps with a certain

type of vocal cord adjustment, which brings about that quality in the singing voice Mme. Mathilde Marchesi spoke of as the "*voix blanche*":

FIG. 145

FIG. 146

"I recommend the practice of singing in Italian, for the emission of Italian carries the emission of the tone forward, and prevents its direction toward the soft palate. . . . And lend no ear to those that advise you to practise with a smile. First of all, this gives the *voix blanche;* next, it causes the smile to become set, and one never gets rid of it."

This is to what García, her teacher, ascribed it, if by that expression she refers to the same quality he designated as "harsh . . . like the quack of a duck." It was he who noted its presence as most likely to occur on **high pitches** and **loud tones.** Since female voices are much higher pitched, and the Italian "metallic" or "brilliant" front vowels do predominate, this may be one reason why Madame finds that:

"In Italy . . . the male voices are the best, and are much more easily handled than the female voices."

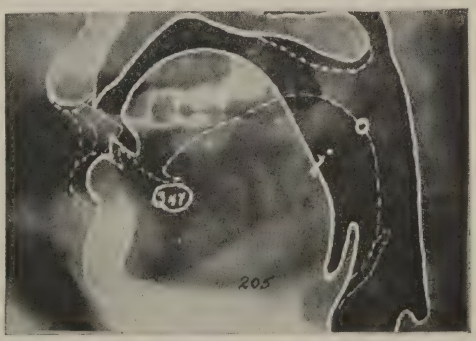


FIG. 147

Fig. 98, for the Italian subject No. 347, shows that even the Italian *a* arches the back part of the tongue in such a way as to slope towards the hard surfaces of the front.

Varying Use of Lips Made by Nordic and Romance Peoples. Those speaking any Romance language make a much more emphatic use of their lips apparently than do any of the more phlegmatic Nordic peoples. The English and Americans are included in this latter category. They are very lazy with their back and forward labial motion; and so "suffocate" their vowels with the soft surfaces of their lips in very much the same way as the aforementioned soft sponge would. The spreading of the lips "as in a smile" and the exposure of the hard surfaces of the teeth would of course tend in the opposite direction. Under such circumstances it would be inevitable that the "tonal quality" would take on a "brilliance" of the same type as that which characterizes the vowel *i* ("peep"). Of that vowel García remarked:

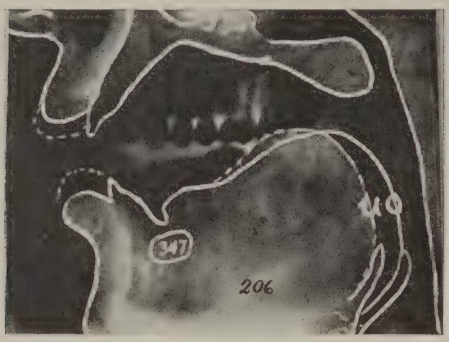


FIG. 148

> "The Italian *i* and the French U (*y*) in the head and high chest notes must be opened rather more than in speaking, or their tint would be unpleasant. Carried to excess, these *timbres* would render the voice . . . harsh . . . like the quack of a duck."

So Process to Be Used Depends on Nationality and Faults of Student. Madame might, therefore, well be right about the smiling position creating the "voix blanche" or "excessively metallic" tonal quality, especially among the Italians and other Romance people. The author himself cannot help but feel that this would depend upon the individual. For such a position might well do much to overcome the defect of one, especially an American, who opens his lips so little that he sings as if he had mush in his mouth, or

FIG. 149

of one whose tonal quality even on front vowels tended to be too "muffled."

Extremes to Be Avoided. It is the extremes which need to be guarded against. And to this end one must exercise precaution against either the soft or the hard surfaces dominating too decisively in their function. Since a narrowing of the soft surfaces tends to "mellow" and make the tone "full," and "round," and "rich," a slight rounding or pulling in of the corners of the mouth can be very beneficial in modifying the quality of a tone which is too "metallic." Much the same result can be better brought about, however, by judiciously narrowing (under a relaxed condition) the soft cavity in the back part of the throat. This, Professor Percy Rector Stephens insists, is by far the best area in which to make the correction, for to accomplish changes in tonal quality with the lips may well lead to facial mannerisms. These soft surfaces are represented not only in the lips, but in the tongue, the velum, the two pillars of the fauces, and the palatine arches (both glosso and pharyngo), or, in fact, in all the soft muscular tissue in the pharynx or back part of the vocal cavity. One should remember, however, that an excessive reduction of the passage between these soft flabby surfaces is certain to lead to a "dull," or even "dead," or "guttural" tone. These surfaces can of course be tensed, and the quality of tone emitted by the trained singer is without doubt, as Helmholtz indicated, largely due to this ability.

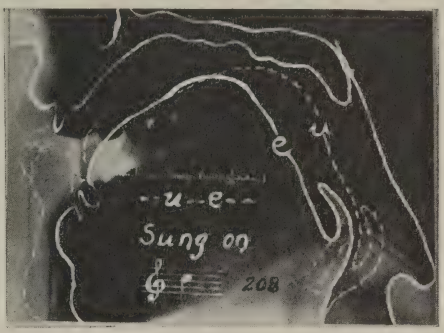


FIG. 150

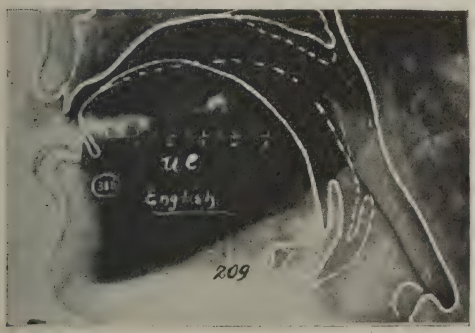


FIG. 151

Such Effects Actually Observed. In a group including some of the foremost singing teachers in the United States (among them Bogert, Fergusson, Klamroth, Lamson, Rogers, Saenger, Stephens, *et al.* who were kind enough to take an interest in these experiments), the author noted most surprising facility of this kind demonstrated in trained voices. Many voice teachers note this function primarily as it affects the velum, and ascribe such quality changes to the effect of its raising and lowering. But the other muscles are quite as much involved. All would probably agree with Mme. G. Delle Sedie [9] that it is advisable to :

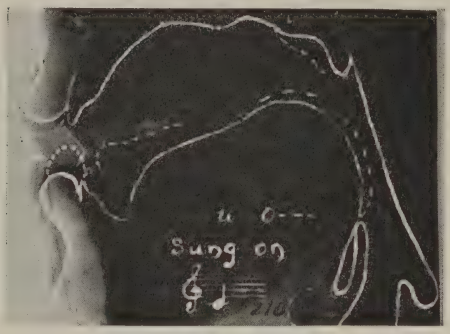


FIG. 152

> " promote the suppleness of the movements of the veil of the palate and of the tongue, to attain by this means a proper emission of the voice, by broadening and narrowing the isthmus of the throat and of the buccal cavity, in order to obtain all the shades of the timbres required for expressive song."

SUMMARY

Cavity Surface Effects. Whereas **soft surfaces** " *mellow* " the high partials or the piercing quality in a tone, and may " *deaden* " it, **hard surfaces** accentuate the high partials and make the tone " *bright* " or what is described as " *resonant,*" or " *clear* " and " *ringing.*" If this accentuation of the high partials is carried to extremes, especially on high pitches and loudly sung notes, the effect becomes excessive and the high partials become " *metallic* " like the *tin-panny* piano, or " *harsh like the quack of a duck.*"

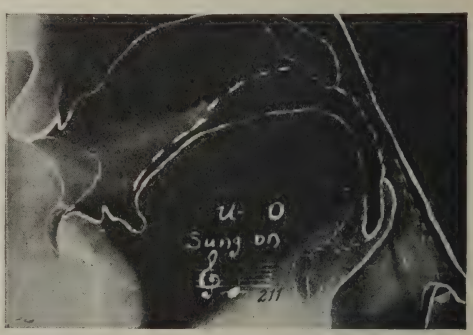


FIG. 153

[9] See her *Esthétique du chant et de l'art lyrique.*

If the back cavities are narrowed, the first or mellow-dead effect is obtained because the surfaces there are soft. Narrowing the lips does likewise. The result is modified somewhat if these surfaces are tensed.

FIG. 154

If the back cavities are spread wide and the tongue sloped forward toward the hard palate, and the velum lifted, with the pillars and other muscular surfaces tense and the lips out of the way, the latter or " resonant " — white tone — blatant — metallic — qualities are brought about in their progressive order, since hard-surface involvement as heretofore indicated predominates.

Glottal and Laryngeal Effect. All of this postulates, however, the presence of this type of tone in the glottal complex before it enters these cavities. Their function is to modify it. The ventricles of Morgani, the false cords, and the cushion of the epiglottis may play a very important part in modifying its inception. These processes seem to be much the same as the ones indicated above. For as the pitch sinks lower and lower the damping gets more and more; until when the voice begins to approach the " growl " the opening between the damping soft surfaces above the vocal cords is reduced to a size little larger than a pin head (passing through a position resembling Fig. 14).

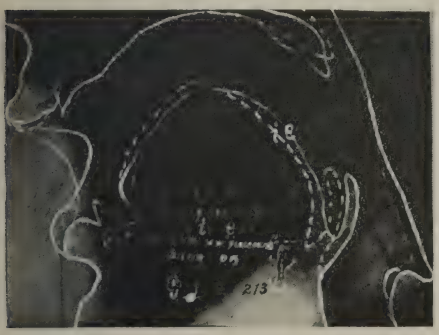


FIG. 155

Observed in Laryngo-Periskop. On clear timbres the author's laryngo-periskop shows a distinct spread and free unhindered vibration with the cushion of the epiglottis well anterior and out of the way. (As in Fig. 17.)

A striking change takes place on reaching a " strained forte " or what

so many singing teachers call (more especially when the tone is produced on a very high note) a " tight voice " (perhaps the extreme " voix blanche " spoken of by Mme. Marchesi). The epiglottis curls in sidewise in a strangling position; the whole interior of the larynx is seen to tighten; and most noticeable of all, the false cords are seen to impinge forcibly on the true cords. They get so tight that they blanche, and of course by their pressure alter radically the manner of vibration noted in the true cords. Withal the cords are barely seen. (Photographed in Fig. 24.)

" Tight Tone " Not Due to Tongue Getting into Back of Throat. This is probably what made the singer think formerly that the " tongue was getting into the back part of the throat " — an impossibility as the tongue seems (if we include its position down by the epiglottis as back in the throat and judge by these experiments) to take this position regularly during the production of the *a* (" ah ") and ɔ: (" aw "). So the real cause of such vicious quality is to be sought farther down.

a (ah) (Study Figs. 56, 57, 66, 75, 83, 84, 85, 86, 98, 103, 111, 136; and compare 123 with 124; 144 with 149; and 166 with 167).

ɔ: (aw) (Figs. 55, 67, 76, 88, 112, 125, 126).

æ (cat) (Figs. 95, 110, 122, 135).

ə (uh) (Figs. 53, 68, 77, 87, 113, 127, 139).

u (fool) (Figs. 142, 143, 145, 146, 148, 150, 151, 152, 153, 154).

ʊ (foot) (Figs. 71, 78, 92, 114, 129).

o (tone) (Figs. 54, 69, 79, 89, 90, 99, 104, 115, 128, 170).

i (peep) (Figs. 58, 62, 72, 81, 96, 101, 106, 117, 162; — 144, 146, 147, 149, 154, 155).

ɪ (pit) (Figs. 63, 73, 82, 107, 118, 132).

e (mate) (Figs. 60, 64, 74, 93, 97, 102, 108, 119, 133, 164, 143, 145, 150, 151, 155).

ɛ (met) (Figs. 61, 65, 94, 109, 120, 134, 165).

CHAPTER XVI

THE MUSIC AND PHYSICS ASPECT OF VOICE QUALITY

"König has also examined the question of the dependence of quality upon phase relation, using a special siren of his own construction.[1] His conclusion is that while quality is mainly determined by the number and relative intensity of the harmonic tones, still the influence of phase is not to be neglected. A variation of phase produces such differences as are met with in different instruments of the same class, or in various voices singing the same vowel. . . . To me it appears that these results are in harmony with the view that would ascribe the departure from Ohm's law, involved in any recognition of phase relations, to secondary causes."

— Rayleigh (1878–1926).[2]

"The quality or '*timbre*' of the human voice, I believe, is due in a very minor degree to the vocal cords, and in a much greater degree, to the shapes of the passages through which the vibrating column of air is passed. As the shape of the passage above the vocal cords controls the quality or *timbre* of the voice, we may be sure that the . . . ventricles, also, the spaces between the true and false cords on either side, should, theoretically, exert an influence upon the quality of the voice, for they constitute two small resonance-chambers, situated close to the source of sound. In the howling monkey the ventricles are expanded into pouches, and the characteristic howl produced by the creature is due to the resonance of air in those chambers."

— Bell (1907–1916).[3]

Break with Customary Views. It seems almost incredible now that anybody should ever have so decried, as Bell does above, the influence of the vocal cords in varying the quality we hear in different voices. Yet physicists and others little acquainted with the physiology of speech are still prone to assume this quality is due solely to the total volume of air in the resonator or resonators which lie above the vocal cords; although there are so few of them which could be used at one time, and quality differences as we know them require a modification in partials which these few could not possibly bring about. Then why disregard other quality modulators?

Physiological Sound Filters. It is astounding that so little attention should have been paid to the possible influence of varying hard and soft

[1] Koenig, R. *Wied. Ann.*, XIV (1881), p. 392.

[2] Rayleigh, J. W. S. *Theory of Sound*, last ed. (1926), Macmillan, London, p. 469.

[3] Bell, Alexander Graham. *The Mechanism of Speech*, 8th ed. (1916), Funk & Wagnalls, New York, 1916, pp. 9, 11.

surfaces; and likewise that the complex structure represented by the vocal cords themselves and the interior of the larynx should have been relegated to such a secondary position.

Differing Quality Produced by the Sound Source — Loading, Clashing. In view of what we knew about the effect of loading a piano string or of loading the reed in an organ pipe by attaching a little lead ball or drop of sealing wax to it — the otherwise mellow tone is thereby made harsh and disagreeable — is it not surprising that no one should have seen how a similar loading of the vocal cords might change their quality?

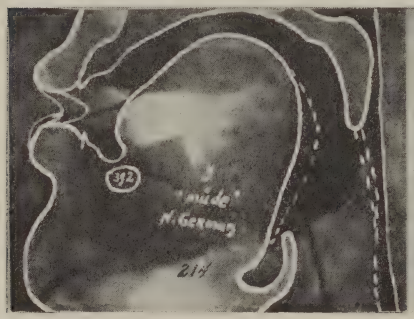


FIG. 156

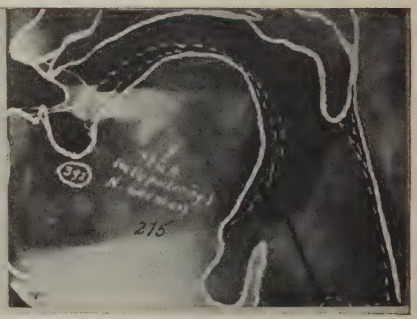


FIG. 157

Knowing as we did the effect on quality of various types of tone stimulation, is it not peculiar that nobody should have called attention to the possibility of the vocal cords themselves altering their own concomitant of partials? It is true that García and Helmholtz, perhaps others also with whom the author is not acquainted, threw out hints, but even these have been generally overlooked. How odd that everybody apparently chose to disregard the manner in which the soft surfaces of the back throat and larynx might muffle sound, and especially the higher partials, by pinching it in and forcing it to escape through little orifices only after it had run the gantlet of muffling soft surfaces. It is especially the more surprising in view of what we knew of the effect of curtains, felt, and of other soft deadening surfaces in broadcasting rooms, theatres, etc.; and of what we knew of the effect of shouting into the bung-hole of a barrel, or of standing off and listening to a sound which has to escape through a long narrow pipe of any kind of material whatever.

What a Sound Is. Many of these questions we have already con-

sidered at length. So this chapter can serve primarily as a summary of the fundamental facts which need to be known in regard to the causes of quality or timbre differences in general. Perhaps it will not be amiss to begin the consideration of this subject by noting that all sounds manifest certain characteristics which we summarize in the terms: **pitch, loudness, duration** or **quantity,** and **quality** or **timbre.** No sound can exist without all four of these factors being present; though in the perception of pure tones and other like sounds, the effect of one or the other may be partially subjective.

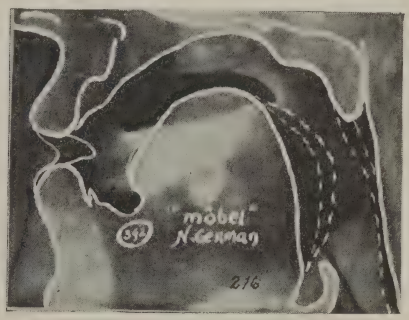


FIG. 158

Pitch is caused by the number of times energy pulsations impinge upon the ear drum in a second. If there are a great number of these oscillations, we say the pitch is *high;* if a few, that the pitch is *low.* The French also use the words *acute* and *grave* respectively for high and low, and these two terms have been carried over by some into English.

Loudness or **intensity** is caused by the relative amount of energy which backs-up or propels this train of waves. In other words it represents the force with which the energy pulsations strike the ear drum. When we see a little ripple in the ocean which makes but a very slight up and down motion we know that it is propelled by much less force than a towering wave. If we record a speech wave by means of a lever which rises and falls with its pulsations we can measure this intensity as well as both the pitch and duration. If a train two cm. long represents one-tenth of a second and shows sixteen crests we know that sound has a pitch of 16×10 or 160 complete or double vibrations (which we often call cycles) or in musical terms that it has a pitch corresponding to the tone we call *E* below middle *C*. The height of the waves which we term the amplitude indicates the intensity or loudness.[4] So we speak of a sound as being *loud* or *strong, weak* or *faint;* as having *carrying power,* or *falling flat;* and the term *resonant* as often used, especially by singers, refers incorrectly to nothing more than the loudness of the sound. (However,

[4] We need only note that as the pitch gets higher it takes less height or excursion in the wave to produce the same loudness.

it should be noted that as singers use it, *resonant* refers to a rich, full, ringing quality, etc.)

The **duration** or **quantity** of a sound is represented in the length of time it takes the train of waves to die down, trail off into nothingness, and diminish to the point where they are no longer perceived and interpreted by the ear or until they are otherwise interrupted or brought to an end. This time we classify under the terms *long* and *short.* Aspects thereof are also represented in such designations as: to *bark, snap out, drawl,* or *prolong* a sound, make it *staccato,* etc.

The **quality, timbre,** or **clang** of a sound is created by a fusion of varying pitches of different relative loudnesses much as is a chord struck on the

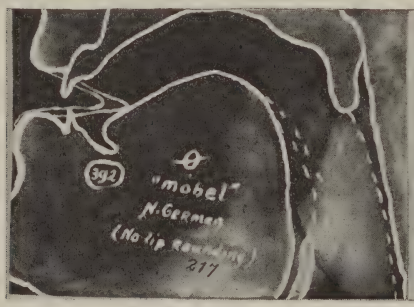


FIG. 159

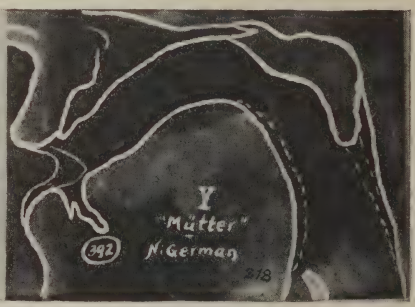


FIG. 160

piano. The resultant is therefore conceived of as a single sound and is so transmitted to the ear. There it is perceived as having a quality which varies just as minor and major chords vary. In speech and singing we use various terms to designate the qualities we hear in a sound, such as: *mellow* or *rich; metallic, clear,* or *bright; dull* or *dead; ringing, sharp, white, cutting, strident, shrill, blatant,* etc.; *full, sweet, mild, soft; poor, faulty, thin, whining, sharp, piercing; dark, deep, barrel-like, hollow, guttural; whining, flat, throaty, pinched, tight, constricted, nasal; nasal twang, nasality, nasal resonance; resonant, "correctly placed," powerful, vibrant; smooth, harmonious, pleasing, velvety; head, chest, throat, covered, open, closed, modulated, flexible, melodious, orotund,* or *pectoral.*

Quality Differences and Family Resemblances. What is the cause of the difference in quality of the speaking voice we hear in two different individuals? It is alike in no two individuals; but it is also true that

certain family resemblances are often recognizable. Then, too, some qualities are pleasant and others disagreeable; some represent culture, while others show a boorish lack of all that is refined.

In Singers. What is the cause, for example, of the difference in tonal quality of the singing voices of two well-trained sopranos? What determines the effects good singers are able to produce by utilizing different qualities? No one will deny but that the voice of every singer has a distinct personality which is quite unlike that of any other. No two seem to be alike; yet how often we are able to recognize unerringly such and such a singer as having been the student of so and so, even though the outward mannerisms have disappeared. Besides, one soprano will have a clear bell-like quality in her voice that is the despair of another who has had, perhaps, much better training. Another singer's voice will have a sharp, cutting quality which perturbs her teachers. Still some other will have a flat quality which militates strongly against her success.

As between Vowels. It is evident that these qualities must be closely allied to the distinctions in difference manifest between vowels. So a study of one quality involves a study of the other. Some vowels have a **ringing, vibrant, metallic,** or **white-**tone quality, such as the "ee" (*i*). At the other extreme stand vowels with a **rich, mellow,** or even **dull** quality, such as the "oo" (*u*). There are others with a **rich, resonant** quality like the "ah" (*a*). Some have a **flat** more or less **unmusical** quality like the *æ* in "bat," or are otherwise **inharmonious,** something like that in the vowel "er" (ər).

Harmonious Relationships Demanded by Nature. It is a curious thing that our civilized ears should demand that fused tones be made up of units that are multiples of each other in order to affect us as being *smooth, harmonious,* and *pleasing,* or in other words what we call *musical.* That is to say, the arrangement must be orderly. When an unsymmetrical mass of tones is flung at us we call it *noise* and are displeased, as we would be with the disorder and filth in the unæsthetic house of a slattern.

Inharmonious Qualities. We recognize differences in the voices of people. We recognize differences in the voice quality of even trained singers. Some are more pleasing than others, some are more disagreeable. In other words, certain inharmonious noise qualities are present in some

voices. There is the woman with a high-pitched, piercing, strident voice that cuts everybody to the quick; or the one with a cutting, nasal twang which seems to carry just as far, and makes cold chills run up and down every hearer's back even though he were a block away. In almost every one of my large classes I find girls with harsh, rasping, low-pitched voices, that sound sometimes almost as bad as the abused guttural voice of the most low-down and uncultured men I have heard down on the East side in New York or in front of saloons and other such dives abroad.

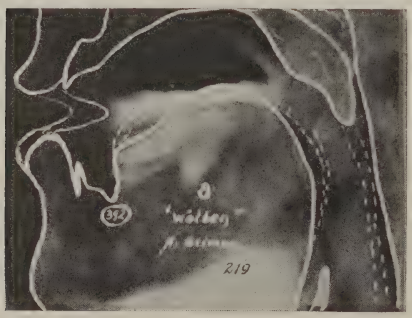


FIG. 161

Voices which impress others as being so disagreeable, like crude and ungracious manners, are inevitably taken to represent an uncultured individual, and for the same reason. After all, that is what the exterior forms of culture are intended to prevent — a disagreeable impression on others. Since we all have to live together the thoughtful individual of culture tries to "step on other people's toes" as little as possible, and considers it his business to make life as pleasant as possible for those who have to associate with him. The creation of a pleasing quality in the voice cannot do other than serve such a desirable purpose. But how may this be secured? In other words, what is the physiological process involved in the creation of this disagreeable quality? This is the question.

Questions on Vowel Quality Also Those for Voice. We have said that all the tonal qualities heard in vowels, and speaking and singing voices, must be more or less closely allied, since they are all manifestations of tone production in the same instrument — the human vocal organ with its generator, and above this its modulators. So an answer to one bears on all the above questions. What is the answer?

The Physics of Quality. It is one thing to consider the physics of this difference and another to fix its physiological cause. We know a great deal about the physics and practically nothing about the physiology of the differences in quality creation here involved. What we actually know about the physiology has already been discussed, and that repeatedly in the various preceding chapters of this book. So to close our

discussion perhaps we had better turn to a consideration of the laws of physics which are involved.

Laws. Ohm's [5] statement of the law of tone quality was summarized by D. C. Miller as follows : [6]

> " All musical tones are periodic; the human ear perceives pendular vibrations alone as simple tones; all varieties of tone quality are due to particular combinations of a larger or smaller number of simple tones; every motion of the air which corresponds to a complex musical tone or to a composite mass of musical tones is capable of being analyzed into a sum of simple pendular vibrations, and to each simple vibration corresponds a simple tone which the ear may hear." [7]

FIG. 162

FIG. 163

To this Helmholtz added another law, which for the sake of uniformity we had better cite again in Miller's [6] words :

> " the quality of a musical tone depends solely on the number and relative strength of its partial simple tones, and in no respect on their differences of phase."

However, it should be noted that certain recent evidence has indicated that this latter statement may have to be modified or qualified. These are the two simple laws of physics which explain the why and the how of all differences in tonal quality, whether they are produced by mechanical

[5] See Helmholtz. *Sensations of Tone* (Ellis translation), p. 126.

[6] Miller, D. C. *Science of Musical Sounds*, Macmillan, N. Y., 1922, p. 63.

[7] Ohm, G. S. Articles in *Pogg. Ann.*, LIX (1843), p. 497; LXII (1844), p. 1. See also Dellmann, F., *Die Harmonie der Einzeltöne und das Ohmsche Gesetz*, Kreuznach, 1867. Also the spokesman for Ohm, Seebeck, A., articles in *Pogg. Ann.*, LX (1843), p. 449; LXIII (1844), pp. 353 and 368. For somewhat conflicting viewpoints, see Stumpf, C., *Tonpsychologie*, Leipzig, 1890, especially pp. 525 ff. and 383 ff.

musical instruments or by the living human voice. To these we may add (in Miller's words) by way of comment, another manifestation which may be thought of as a subjective addition thereto :

> " Analyses . . . give abundant evidence that tone quality as perceived by the ear is much influenced by subjective beat-tones. While these tones may be considered as having no physical existence yet their effects upon the ear are those of real partials, and the laws already stated include them."

In **summary,** these laws state that quality is dependent on the pitches, relationship, and loudness of the partials perceived by the ear in a complex tone.

Let us take now some specific qualities and see the application of this principle or group of laws.

A **hollow** tone, according to *Helmholtz* (stated in the words of *Ellis* [8]), is one in which " only the unevenly numbered partials are present as in narrow stopped organ pipes."

A **nasal** tone is one in which " a large number of such " (unevenly numbered) " upper partials are present."

A **rich** tone results " when the prime tone predominates."

A **poor** or (**thin**) tone is created " when the prime tone is not sufficiently superior in strength to the upper partials. Thus the quality of tone in the wider organ pipes is *richer* than that in the narrower; strings struck by pianoforte hammers give tones of a richer quality than when struck by a stick."

A **cutting** tone is produced " when partial tones higher than the sixth or seventh are very distinct. . . . The reason lies in the dissonances which they form with one another."

F. Auerbach,[9] the most outstanding living student Helmholtz had, and one of the foremost physicists in the world who has dealt with the subject of acoustics and speech, or scientific phonetics, summarizes as follows :

[8] Helmholtz. *Sensations of Tone* (Ellis translation), 4th ed., Longmans, Green and Co., New York, 1912, p. 119. Italics and material in parentheses mine.

[9] Auerbach, F. "Akustik," 2nd ed. (1909), being the second volume in Winkelmann's *Handbuch der Physik*, Leipzig, p. 263. (Translation; italics; placing of certain words in black; parentheses; the optional English terms; and the explanatory term "brightness" in "4" are all mine. Most of the material in parentheses is either an attempt to better express his idea or but a summing up of what Auerbach has said in various places.)

"**Mellow** = Fundamental alone;
Rich = Fundamental with the first overtones;
Broad (or **spread out**) = Fundamental with many overtones;
Sharp = Fundamental with high overtones;
Full (or **round**) = Fundamental paramount or dominant;
Thin (or **empty**) = Fundamental dominated by the overtones (but is also used at times to describe the quality of an isolated fundamental or strictly pure tone);
Nasal = Odd numbered partials only;
Hoarse (**guttural** or **harsh**) = dissonant overtones, especially lower;
Shrieking (or **screaming**) = dissonant high overtones;

FIG. 164

FIG. 165

"1. *Simple tones* (tuning forks with resonator mountings and stopped or covered organ pipes, etc.) sound very **mellow** and pleasant, without any harshness, but **weak,** and where deep, **dead.** . . .

"2. *Lower overtones up to the sixth accompanying* in moderate loudness, sound more **sonorous** and therefore more musical; compared with a pure tone they have something more **rich** and **impressive** but are, however, entirely pleasing and **mellow,** so long as the higher overtones are missing. (These are produced by grand pianos, open organ pipes, the soft pianissimo tones of the human voice, and of the French horn, which latter begins to approximate the transition to the quality produced by higher overtones; on the other hand, the flute, and the lightly blown flute pipes of the organ begin to approach the simple tone quality.)

"3. *Odd numbered overtones* (present in the tone produced by narrow stopped organ pipes, piano strings struck in the middle, and in clarinets) produce a quality which is **hollow.**

A large number of odd numbered overtones give a **nasal** clang.

If the *fundamental predominates,* the quality is **full** or **round.**

Where the *fundamental is not enough stronger than the overtones* it sounds

thin. (So the quality of wide, open organ pipes is **fuller** than the narrow; the quality of strings, **fuller** when they are struck with the soft felt piano hammers than with wooden, or when one rips along them with the finger nail; and finally the tone of reeds accompanied by pipes tuned to the same, is **not** so **thin** as where the reed is blown alone.)

" 4. *Overtones higher than the sixth or seventh,* if very outstanding, produce a quality which is **sharp** or **harsh,** depending on the proximity of these overtones, and corresponding to the sharpness of the corners in the curves produced by the same. Consequently the degree of sharpness may vary considerably; where their *loudness* is *not too great* these overtones do not impair the musical quality materially, but are rather advantageous " in adding **brightness** " and give character and expression to the music. (Of this type, the tones of the bowed string instruments, most reed pipes, oboe, bassoon, reed organ, as well as the human voice, are especially important.)

" (The harsher crashing quality of the brass instruments make them extraordinarily penetrating, and give, therefore, an impression of greater loudness than the sounds of mellower nature. In and of themselves they are therefore but little adapted to artistic music, but are of great value in an orchestra — and we may add — particularly valuable for special, *e.g.* military purposes.)

" 5. *Sounds with a large number of* (in part) *inharmonic overtones,* have a quality which approximates in progressive degree that of **noise,** wherein the identity of the pitch is more and more lost. . . . (To these belong all those instruments whose sound system has not only one but two dimensions, such as the drums, kettle drums, and cymbals.) And if one goes farther in the same direction he comes to the real noises."

Quality Studies in Ohio State Phonetics Laboratory. By means of electrically constructed sound filters and networks of various kinds it is now possible for us to make a more accurate study of this question of sound quality; [10] for we may pass the speech or singing of any individual through such a system and alter it at will, and in the meantime study any

[10] At this point, the author wishes to acknowledge his indebtedness to the demonstration of the first experiments of this type he had the privilege of listening to, conducted in the research laboratories of the Bell Telephone Company under the direction of Dr. Harvey Fletcher. He knows of no published material of the type above cited, showing quality analyses, to which he could cite the reader. Nor companies from which filters may be purchased. Those used in our laboratories had to be constructed there since we could not get them elsewhere. In passing, attention might also be called to the fact that it is possible to construct mechanical filters and accentuating networks which give most interesting effects. The phonetics laboratories at Ohio State now have under way certain experiments of this type in which cavities modelled from X-ray photographs are being lined with porous sponge rubber, beefsteak, wet cotton, water-impregnated bone, etc. And others made of metal and rubber tubing to which are attached mazes of resonating cavities in parallel and series, which operate to favor given pitches, producing a final resultant in which these stand out over the balance of the partials present in a complex sound passed through the system. Since the above went to press Dr. Fletcher published his book, *Speech and Hearing* (Van Nostrand, N. Y.), containing some very interesting material bearing hereon, and many radio companies have started manufacturing electric filters.

effect thereby produced. The author's impression of the changes in quality created by the systems constructed and installed in his own phonetics laboratories at Ohio State University at Columbus, Ohio, is as follows:

FIG. 166

FIG. 167

Filters cutting-out frequencies.

Below 250 cycles per second = slight modification of voice quality. *Robs the voice* of some of its so-called "**resonant**" or **full, ringing richness.** But it is still perfectly natural. And curiously enough the hearing of most observers seems to be unaware of any pitch change in the fundamental. In other words, the voice pitch is not heard as an octave higher. The partials and difference tone give the ear a subjective impression of the same fundamental even though the latter is filtered out. This may account for the same observation made by early scientists in a study of phonograph records. For the phonograph used may not have recorded the fundamental in consequence of its frequency characteristics, even though the same was used by the subject; yet it would apparently be heard by observers who listened to the record though a harmonic analysis of the curves on the record showed the fundamental to be absent. (See Scripture's studies.)

Below 500 cycles = *nasal tightness of tone.* Voice seems to begin to recede into the background as if coming from a distance. But oddly enough most observers still do not hear it as changed to a feminine voice; yet the lowest frequency present is well up in that range.

Above 5000 cycles = voice quality satisfactory. Some speech sounds partly eliminated.

Above 3500 cycles = *mushy throatiness* of quality, which begins to be very disagreeable.

Above 1500 cycles = **muffled, dead,** and **lifeless** tonal quality. When

the filter is shunted in, the resultant sounds exactly as if a hand had been clapped over the speaker's mouth. Yet the speech is still understandable.

Above 1000 d.v./sec. = **muffled, dead, mushiness.** Sounds just as if one had jammed the individual's head into a stovepipe, or covered his mouth with the bung-hole of a barrel. The speech is no longer readily understandable.

If we **inject a network which accentuates certain partials,** we also note characteristic changes in quality; and these are even more interesting because much the same thing might be accomplished in the physiological mechanism.

Emphasizing the partials
Above 5000 d.v./sec. = **metallic, piercing quality.**
Above 3500 cycles = **gurgling, metallic, nasality.**
Above 2500 d.v./sec. = **typical New England nasal twang.**
Below 500 cycles = **fullness** of tone, **rich, "resonant."**

If first we **inject a phase distortion** into the low-pitched partials without molesting the high, and then reverse the result, or if we boost the whole gamut of partials by say thirty cycles each, we create varying inharmonious results which sound something like the variable loading of two simultaneously sounding but otherwise harmoniously tuned piano strings. We hear these qualities daily in the voices of people around us. The author's laryngo-periskop, or fonofaryngoskop, shows that the human voice accomplishes a low-pitched **hoarseness** or **gutturality** analogous to that mentioned below which was artificially created, by an approximation of the false vocal cords (ventricular bands) with a resultant vibration of saliva especially in the pinhead opening located posteriorly over the arytenoid wedge. A high-pitched **stridency** or **piercing, blatant** quality may be created by tension in the whole interior laryngeal muscular surfaces above — brought about by an impingement of the ventricular bands which are thus forced to press down on the vocal cords. This impingement takes place along the outer periphery or laryngeal attachment of the vocal shelves in such a way as to leave only the narrowest strip of the inner blade-like edge of these vocal wedges free to vibrate, thus undoubtedly forcing them to strike violently together cymbal-like, or in other words loading them in such a way as to accentuate

inharmonic higher partials.[11] All this is treated more in detail elsewhere herein.

Physiological Filters. What are the physiological equivalents of these filters and networks which are thus seen to alter so radically the quality heard in a sound? These quality differences represent tonal distinctions which are precisely analogous to what the singing teacher designates under the terms: good or bad " voice placement " or " resonance." If we can artificially create such changes in tonal quality through the use of filters and modifying media which take out or accentuate certain partials in the complex voice sound passed through them, does it not follow

FIG. 168

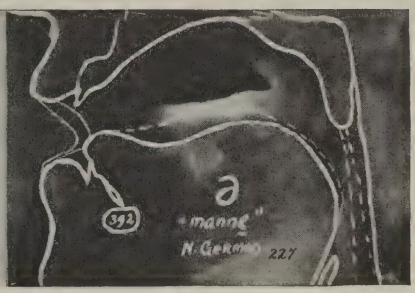


FIG. 169

that nature's physiological filters and accentuators might conceivably be regularly involved in accomplishing the same result?

The resonating air volume immediately above the vocal cords, with exits at the lips and nostrils through which the sound finally passes, undoubtedly plays a part similar to that played by cavities in all wind instruments. A cavity open at both ends will respond to all harmonics, both odd and even; but if it is closed at one end it will respond only to the odd ones, that is, to the fundamental or cord tone and to every other harmonic thereafter after skipping the one immediately following the fundamental which would be the octave or first overtone. We know that certain differences in quality between organ pipes and wind instruments are caused by reason of these two varying types of cavities. And naturally they would do the same in the human mechanism if the very irregular

[11] I say undoubtedly, but actual evidence waits on the perfection of rapid moving pictures or single snapshot pictures, which will show the exact position at any given phase in one instantaneous exposure. In the Ohio State laboratories we are now making the attempt for the American Academy of Teachers of Singing on a limited Carnegie subvention.

voice cavities actually responded just as does the perfectly regular pipe. But do they? Does the spherical resonator? Of course if they did, the lower cavity might possibly be considered as being closed at its lowest extremity though there has been considerable debate as to whether the vocal lips themselves could be considered as closing it. But where the tongue arches against the palate, or a narrowed opening is created at the velum, the front cavity must be considered as being open both at the lips (Fig. 176 or #4 Fig. 190) and at the back (#23 Fig. 190 and #32 Fig. 198) where the palatine arches open into the pharynx.

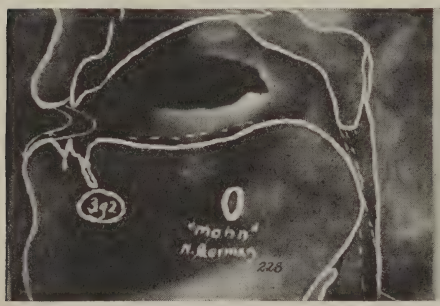


FIG. 170

FIG. 171

If the nasal passages are opened (#12 Fig. 177) they also might be considered as injecting additional tubes which are open at both ends. The latter observation, if divorced from all the other influences which act on the complex sound except that exercised by the air volume resonator represented by the nasal cavity, is of itself disturbing, for these tubes being open at both ends should respond to all partials; yet nasal quality, as was before indicated [12] in the quotation from Auerbach, is heard where the fundamental is sounded with " odd numbered partials only." Then why should the injection of this nasal cavity cause the quality of a sound to become what we call " nasal "? The answer is that it does not necessarily do so. If we close the lips it does, for then the buccal or mouth cavity is closed at one end. Such is the M or a " hum." The tongue closure as for an N does the same thing. If we pinch the nostrils, or get a cold which closes the exit from the nose, the voice, especially if it is resonant and the nasal passages are regularly kept open, becomes " nasal " in quality. But there are finer distinctions in quality provided in human voices

[12] Auerbach. "Akustik," 2nd ed. (1909), p. 263.

than those manifest in these broad differentiations; and the cavities will hardly account for them. Have the surfaces no influence?

There must be certain physiological sound filters provided by the soft surfaces, which when they close in around the tone inevitably operate to muffle not only the complex sound as a whole but especially the high-pitched metallic partials.

1. There are the *ventricular bands* or *false vocal cords* (4) and under each the *Ventricle of Morgagni* or *sinus* (#5 Fig. 192). These seem to operate particularly in the creation of low-pitched guttural and hoarse qualities, when they are loose and flabby and operating as soft-surfaced filters.

2. Above these is the *tubercle, cushion,* or *pulvinar of the epiglottis* (#2 Fig. 192), functioning as a soft-surface filter to lower pitch and mellow the quality in tones when it is coöperating with the cartilages of Wrisberg (#6 Fig. 190).

3. Superior thereto lies the *tip of the epiglottis* which may lie well back against the wall of the pharynx (*cf.* #28 Fig. 190).

4. The laryngo-periskop shows that this narrowing is usually accompanied by a further one between the *root of the tongue* (#27 Fig. 190) and the pharyngeal wall, especially manifest in the production of the "resonant" but mellowed, and still loud vowel "aw" (ɔ) and voice qualities partaking of this nature.

5. These are also usually accompanied by a lateral constriction in the pharyngeal muscles and arches — the *stylopharyngeus* on either side (#28), the *palatopharyngeus* (#27), and often up to the very uppermost opening into the buccal cavity made by the *isthmus of the fauces* (#9 Fig. 193), involving also at times the *levator palati* (#3 Fig. 178), the *palatoglossus* (#28 Fig. 198), and the whole complex muscular structure in that neighborhood, including of course the tongue muscles below, the styloglossus (#1), hyoglossus (#2), and genioglossus (#4 Fig. 179). Together these form the most effective soft-surfaced enmeshing area used in the physiological creation of tonal quality — all together usually spoken of as the *palatine arches,* or simply the *veil* or velum (#24 Fig. 190). Radical constriction in this area is usually noted for "oo" (*u*).

6. The buccal cavity in front of these may again vitally affect tonal quality by narrowing the final exit through which the complex sound has to escape. The main muscles in the lips run round and round, and are designated as the *orbicularis oris* (#9), *quadratus* (#4) *risorius,* and *buccinator*

at the corners (#10 Fig. 176, see also #4 Fig. 175). They serve especially to mellow the metallic high partials, and thereby accentuate the lower partials, thus making the tonal quality rich, full, and what some call resonant. They are particularly involved in the production of " oh " (*o*) and " aw " (ɔ), and tonal qualities which partake of their timbre.

Most of the opposite or " metallic " effect would seem to be brought about by the manner in which the vocal cords themselves function. The surfaces above are, however, often very evidently involved. There is :

1. The decided constriction and impingement of the whole interior laryngeal musculature, one part supporting the other in pressing on the outside edge of the vocal cords themselves, from the *ventricular bands* (#4 Fig. 192) to the tip of the epiglottis, which is made to squeeze forcibly around the same by reason of the pull on the *aryepiglottal* or *arytenoepiglottideus* muscle (#1 Fig. 196), and the *arymembranaceus* muscle (#3 Fig. 191), etc.

2. On the other hand the whole pharyngeal cavity (from #28 to 22 Fig. 190) is forcibly distended to the utmost and all its muscles thereby put under decided tension in this direction for the production of the vowel "ee" (*i*), and tonal quality which verges towards this bright or metallic type.

3. Then for this same vowel " ee " (*i*), and bright, metallic, and where excessive, piercing tonal quality, one regularly notes the accompaniment of a tongue arching against the hard palate (#18 Fig. 190) from the point where the velum joins on to it, up to the hard teeth (#4 Fig. 190). Whether the placement of the tongue tip against, or under the cutting edge of the lower teeth has any effect or not remains to be proved.

In the past some have had a tendency to lay great stress on the possible function of the bony cavities designated as the *sphenoidal sinus* (#2 Fig. 177), especially the *frontal sinus* (#1 Fig. 190) up above the eyes, and the *antrum* or *maxillary sinus* (#22 Fig. 199) on either side of the nose. By many they were supposed to create that voice quality which the singer designates as " resonant," in the same manner that the cavities of the violin, mandolin, and guitar give these instruments their resonant quality. This argument has been so thoroughly exploded by now that it seems unnecessary to treat it here. In the first place they are relatively so much smaller than the cavities of the violin, mandolin, or guitar. In the second, the area is waterlogged. In the third, they have no such sound-resonant openings as are provided over these cavities.

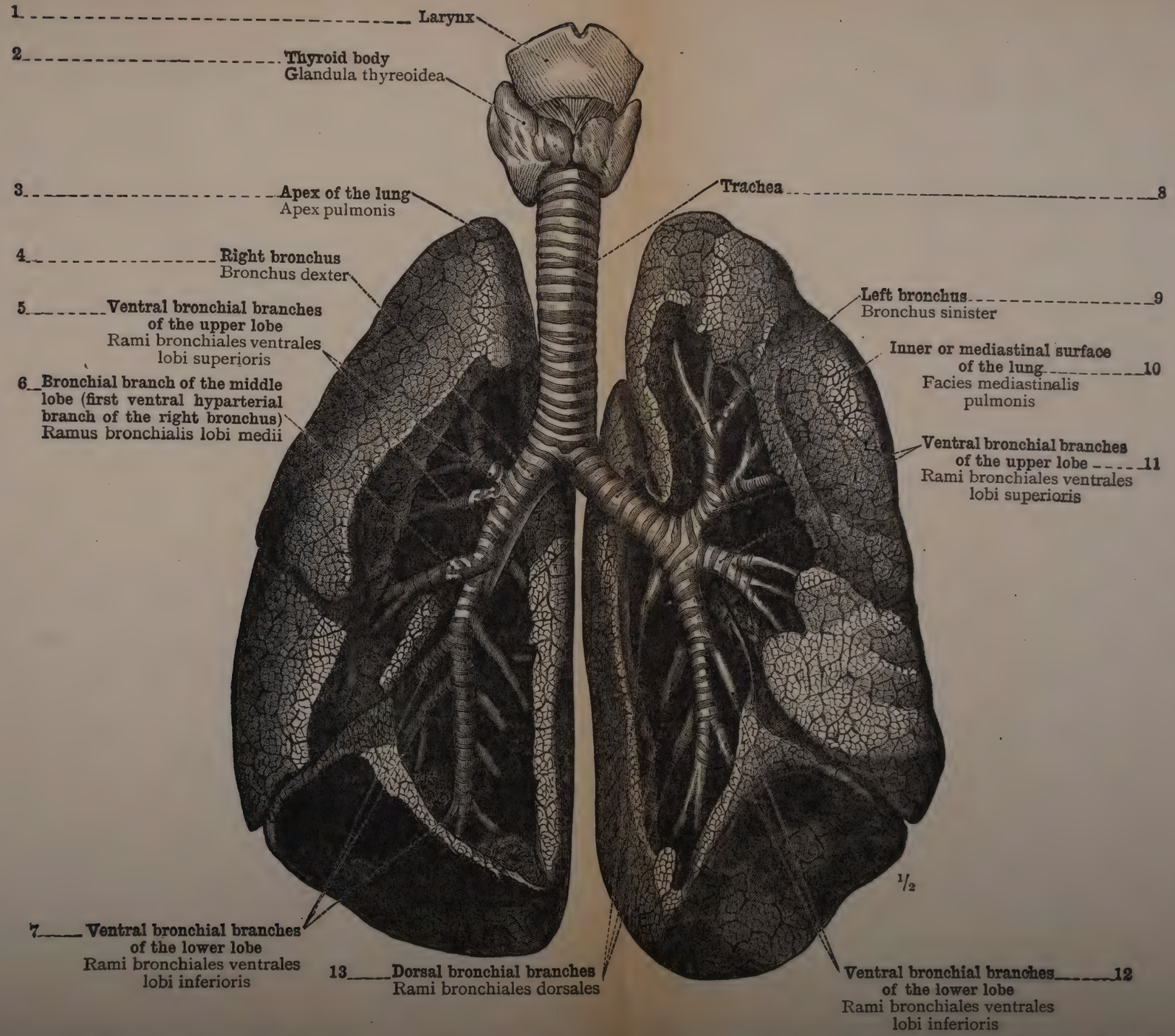

1 Larynx
2 Thyroid body
Glandula thyreoidea
3 Apex of the lung
Apex pulmonis
4 Right bronchus
Bronchus dexter
5 Ventral bronchial branches of the upper lobe
Rami bronchiales ventrales lobi superioris
6 Bronchial branch of the middle lobe (first ventral hyparterial branch of the right bronchus)
Ramus bronchialis lobi medii
7 Ventral bronchial branches of the lower lobe
Rami bronchiales ventrales lobi inferioris
13 Dorsal bronchial branches
Rami bronchiales dorsales
Trachea 8
Left bronchus 9
Bronchus sinister
Inner or mediastinal surface of the lung 10
Facies mediastinalis pulmonis
Ventral bronchial branches of the upper lobe 11
Rami bronchiales ventrales lobi superioris
1/2
Ventral bronchial branches of the lower lobe 12
Rami bronchiales ventrales lobi inferioris

FIG. 172. — THE TRACHEA, ITS BIFURCATION INTO THE RIGHT AND LEFT BRONCHIAL TRUNKS (BRONCHI), AND THE LARGER SUBDIVISIONS OF THESE (RAMI BRONCHIALES). RELATIONS OF THE BRONCHIAL BRANCHES TO THE LOBES OF THE LUNG AND TO THE DIFFERENT REGIONS OF THESE LOBES; SEEN FROM BEFORE.

CHAPTER XVII

MECHANISM OF THE SPEECH ACTUATOR — THE LUNGS

"Science is concerned with *facts* which have been systematized and formulated. . . .

"**Anatomy** is the science of organic structure. Human anatomy refers to the gross structure of the human body. Comparative anatomy compares the structure of the human body with that of the lower animals. The study of anatomy is usually carried out on the dead bodies of animals and plants since it is not concerned with their activity.

"**Physiology** is the science of function. It shows us what the organs do in relation to each other, hence it is concerned with the complete animal, showing the functional relationships of organ to organ in the harmonious behavior of the organism as a unit.

"**Psychology** is the science of behavior."

KIMBER AND GRAY (1927).[1]

Except for a few clicks caused by the making and breaking of contact, it may be said that all normal speech and voice sounds trace their first stimulating source to an energy which originates in a pressure on the *lungs*. This statement, of course, disregards the source of the nerve impulse and refers purely to the physical and mechanical origin of sound in the human mechanism.

ANATOMY OF THE LUNGS

Exterior. The lungs operate like a pair of bellows. The right lung is broader, larger, and heavier than the left, though it is not so long, since the diaphragm rises higher on that side to accommodate the liver under it. The left is also deeply notched to make room for the heart which lies between the pair. The right is divided by fissures into three lobes of approximately the same size — the upper, middle, and lower. The left is divided into two lobes. The sides and top are convex.[1] But the base is concave — both lung curves thus presenting greater surface area against which the ribs and diaphragm can exercise pressure. They

[1] Kimber and Gray. *Textbook of Anatomy and Physiology*, Macmillan, New York, 1927.

extend about three or four cm. above the sternal end level of the first upper rib. (See Fig. 173.)

Interior. The interior of the lungs is quite unlike that of any ordinary bellows, being more comparable to a rubber bath sponge. It is composed of a porous and spongy substance (see Fig. 172), which tends in its live state (for the reasons cited below) always to spring back to normal shape even though it has been squeezed and collapsed. Its pores are air cells (*alveoli*); and by such an arrangement the inside of this relatively small part of the body is made to provide a surface exposed to the air which is estimated to be one hundred times greater than that of the body's skin. It is evident what a contribution this arrangement of these springy cell walls make to the efficiency of the bellows. (See Fig. 173.)

Structure of Air Passages. Each one of these minute air cells is but a part of a larger hole called an *atrium* (*infundibulum*), out of which leads a small tube (*bronchiole*). This in turn, along with numerous others of the same kind, leads into the main *bronchial tubes* (bronchi). Each lung thus connects by means of one of these *bronchi* with a central tube called the *trachea*. (See Fig. 174.) The bronchial tube of the right lung is shorter, wider, and more nearly vertical than the left. (See Figs. 172, 174.) All these tubes, the bronchioles, bronchi, and trachea, are made up of small rings of extremely tough cartilage — so tough that it is impossible to collapse the bronchi or the trachea, except by smashing them, and even then it would take a hard blow from a hammer to do so.

Not Possible to Vary Their Characteristic Tone. Neither can they be stretched lengthwise. So, as will be seen, the individual is not capable of varying their cavity tone capacity (or the natural vibratory period which would characterize them). Those interested in the physics of speech and song need to bear this fact in mind. Yet because of this ring arrangement, the tube is flexible and it is possible to bend it quite materially in any direction.

How Housed. The lungs are suspended within a space (see Fig. 180) called the chest (*thorax*), which is surrounded by the chest bone (*sternum*), ribs (*costæ*), and backbone (*spinal vertebræ*). They are covered by a closely fitting tissue, designated as the *pleura*. (See #23, 24 Fig. 173.) This same material lines the inside of the chest; and between the inside walls of this latter and the pleura-covered lungs is an empty space. (See #29 Fig. 173.) Therein just enough moisture is provided to permit the

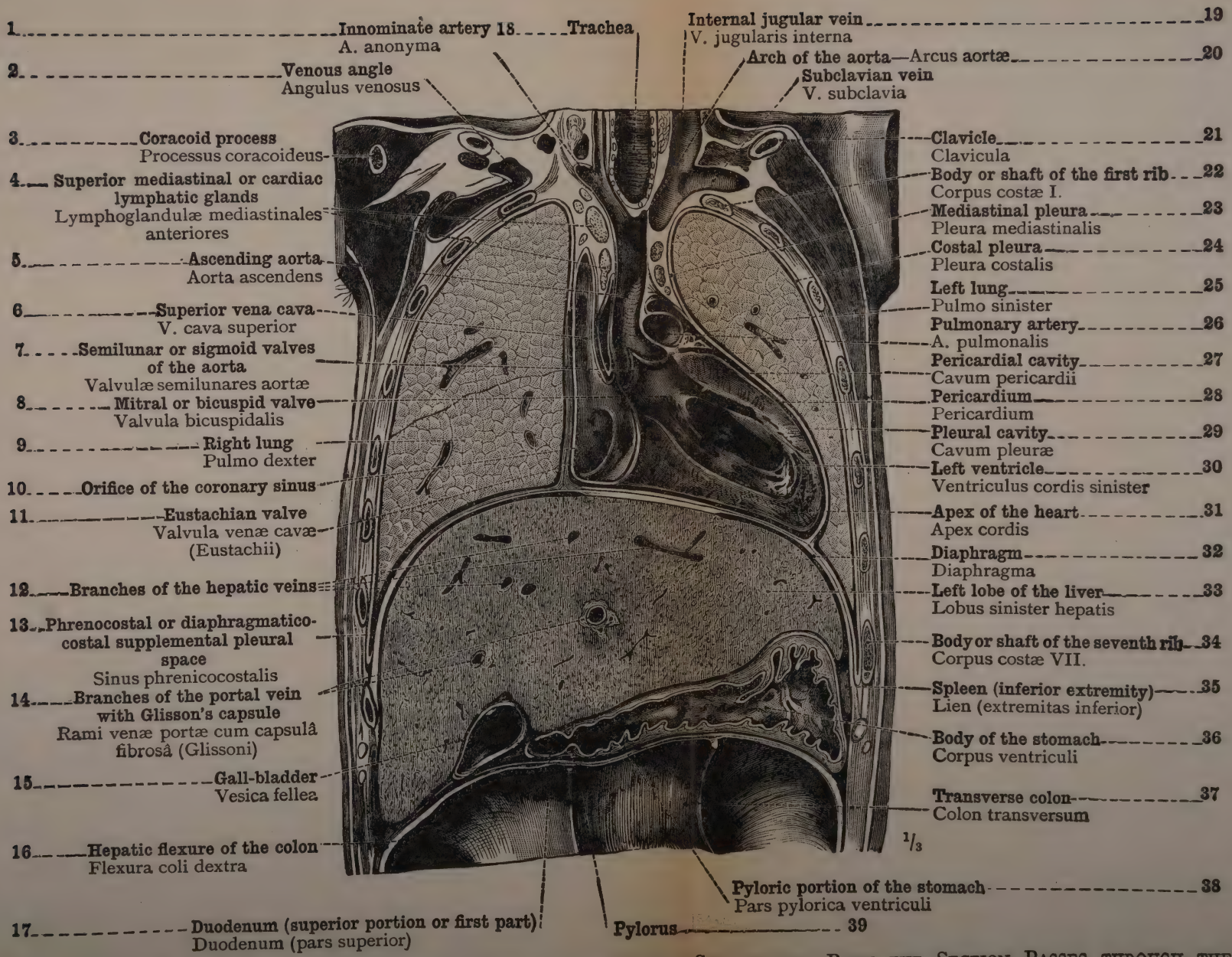


FIG. 173. — CORONAL SECTION THROUGH THE TRUNK: ON THE RIGHT SIDE OF THE BODY THE SECTION PASSES THROUGH THE ANTERIOR ASCILLARY FOLD, ON THE LEFT SIDE A LITTLE IN FRONT OF THIS FOLD.

lungs, when they are filled with air, to slide over the chest walls without friction. It is an admirable arrangement, allowing deep breathing without consciousness of the inflated *air cells*.

Physiology of the Lungs

How the Lungs Function in Sound Production. Now the question arises as to how the lungs themselves function in altering the pressure in the air column required for changes in speech and song. A great deal has been written on this subject, and it is needless to say that most of this is a mere expression of opinion coming from doctors and singing or speech teachers who have some theory to advance. Since our study is intended to present scientific facts, it is evident that the author cannot be expected to take sides in unsupported controversies of this kind. We shall have to be content, therefore, to present nothing more than a résumé of the known facts pertaining to the basic types of muscular control brought to bear upon these bellows.

Control. Between the **ribs** above mentioned, there are eleven *intercostal spaces* on each side. (See Fig. 180.) Each of these spaces is filled with two oblique layers of muscular fibers called the *intercostal muscles*. (See Fig. 181.) The fibers of the *internal* or lower layer run slantwise with the top towards the chest bone (sternum) and the bottom facing around towards the backbone. The upper or *external* layer, which likewise attaches from the rib above to that below, slants in the opposite direction, or in other words downward and inward toward the mid-line of the chest bone (sternum). There are thus forty-four intercostal muscles since there are twenty-two spaces and two muscles to a space.

The external intercostals elevate the ribs, thereby increasing the chest cavity, and filling the lungs with air.

That portion of the internal intercostals which lies between the ribs proper probably serves to contract the chest cavity and hence to expel the air, or in other words to increase the pressure on the air column. But the forward part or that towards the sternum between the part of the ribs designated as the *costal cartilage* probably functions to expand the chest. It is wise to say "probably," because disagreement as to the function of the internal intercostals still persists.

Chest Structure. The reason why the contraction of the external fibers, which slope toward the front center of the chest (sternum), tends

to expand the thoracic cavity (chest) is to be seen in the manner in which the structural framework is laid together. There are twelve ribs on each side, all connected with the vertebræ at the back by strong ligaments which serve to let them operate at that point like hinges. Each pair of ribs is thus pivoted on a separate segment of the rear spinal column (see Fig. 180), which may be held in a fixed position, thus permitting the posterior (back) end of the rib to be bound firmly at that point and yet rotate freely as the front end is raised and lowered.

Ribs. On the other hand, as reference to Fig. 180 will show the reader, a strikingly different arrangement is provided for the attachment of the front end of the ribs. Each pair is radically differentiated in form from the others. The eleventh and twelfth, or two bottom ones, have no attachment at all, and hence are called *floating ribs*. These, along with the others up to and including the eighth, are called *false ribs* because of the fact that none of them actually articulate against the chest bone (or sternum). As will be seen, the eighth, ninth, and tenth are all joined together in front, and attach to the seventh by most peculiar upward-curving cartilages. The seventh is at one point fastened just enough to the sixth to keep the two from rubbing against each other. So the sixth, seventh, eighth, ninth, and tenth are forced to move more or less as a unit.

Bottom Ribs Most Important. Perpendicular Movement. Now these are exactly the ribs whose front ends slope downward most decidedly from the spinal column forwards, and whose cartilage terminations then turn most abruptly and radically upwards. Hence any pull on the muscle fibers of the external intercostals, which slope towards the sternum, will draw this whole lower set upwards towards the fifth rib, and a similar movement will be caused in those from thence on up to the first.

Lateral Distention. But, what is more important, this movement will also *force a radical swing outwards towards the sides, of the sixth, seventh, eighth, ninth, and tenth* (being evidently progressively greater as we move toward the latter or lowest ribs), and a lesser such movement in the other ribs on up to the third.

Anterior-Posterior Distention. Then too, since the sternum (to which all these ribs are bound as indicated) is free to move up and down as a whole, and closer to or away from the backbone, where the rib movement so directs it, the tension of the external intercostals may well result in pushing out the chest bone (especially its lower tip).

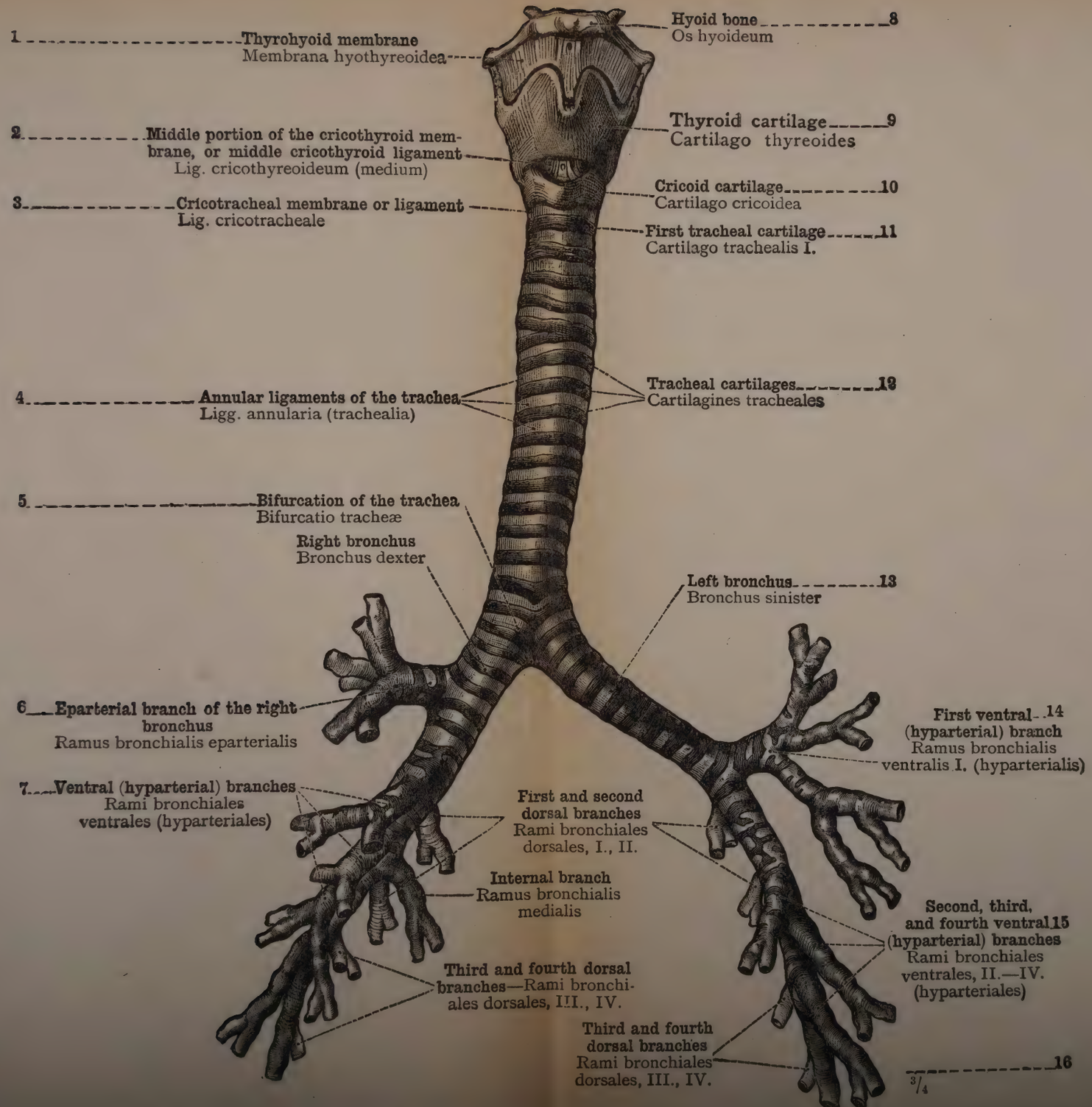


FIG. 174. — THE TRACHEA, ITS BIFURCATION INTO THE RIGHT AND LEFT BRONCHIAL TRUNKS (BRONCHI), AND THE LARGER SUBDIVISIONS OF THESE (RAMI BRONCHIALES); SEEN FROM BEFORE.

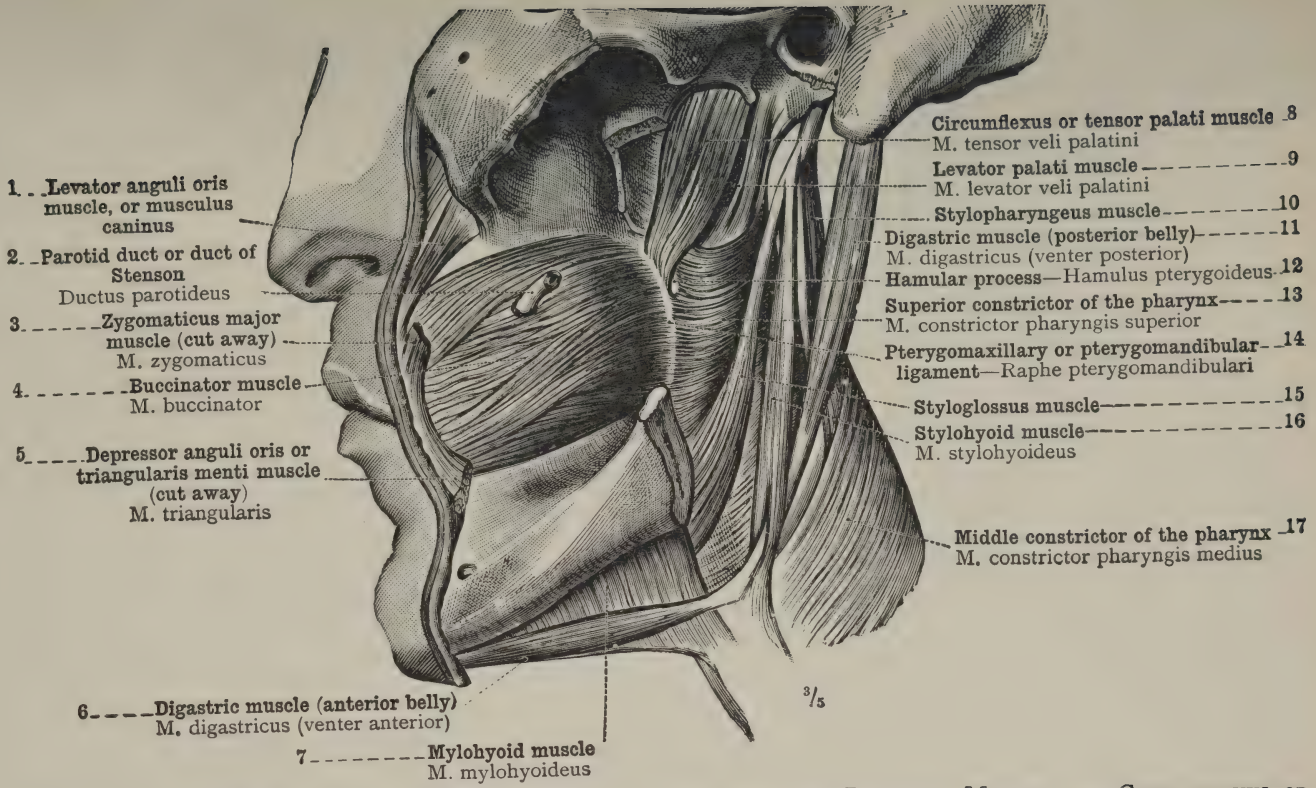
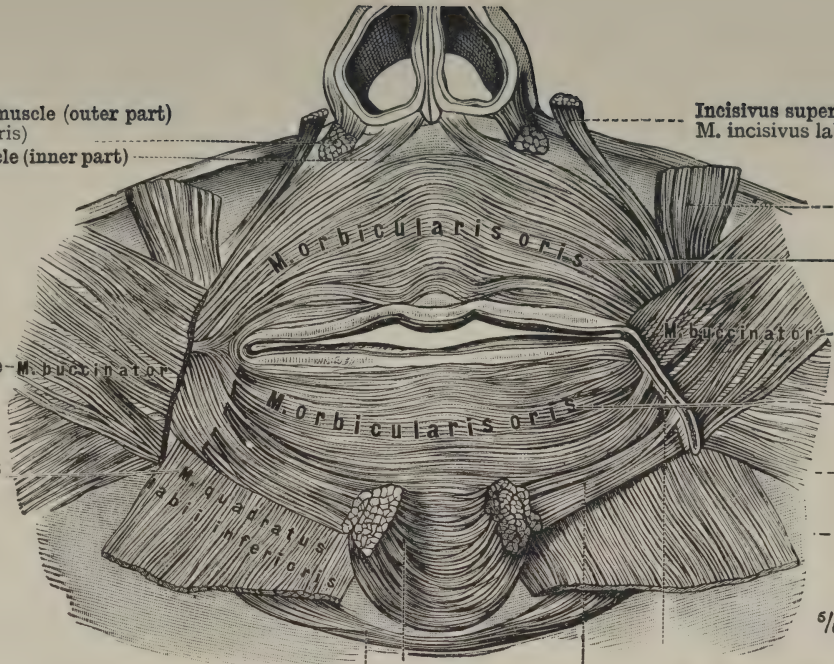

1. Levator anguli oris muscle, or musculus caninus
2. Parotid duct or duct of Stenson
Ductus parotideus
3. Zygomaticus major muscle (cut away)
M. zygomaticus
4. Buccinator muscle
M. buccinator
5. Depressor anguli oris or triangularis menti muscle (cut away)
M. triangularis
6. Digastric muscle (anterior belly)
M. digastricus (venter anterior)
7. Mylohyoid muscle
M. mylohyoideus
8. Circumflexus or tensor palati muscle
M. tensor veli palatini
9. Levator palati muscle
M. levator veli palatini
10. Stylopharyngeus muscle
11. Digastric muscle (posterior belly)
M. digastricus (venter posterior)
12. Hamular process—Hamulus pterygoideus
13. Superior constrictor of the pharynx
M. constrictor pharyngis superior
14. Pterygomaxillary or pterygomandibular ligament—Raphe pterygomandibulari
15. Styloglossus muscle
16. Stylohyoid muscle
M. stylohyoideus
17. Middle constrictor of the pharynx
M. constrictor pharyngis medius
3/5

FIG. 175. — THE MUSCLES ARISING FROM THE STYLOID PROCESS WITH THE DIGASTRIC MUSCLE, THE CIRCUMFLEXUS OR TENSOR PALATI, THE LEVATOR PALATI, AND THE BUCCINATOR MUSCLE; SEEN FROM THE LEFT SIDE.

Total Expansion. So we have a radical expansion of the interior chest cavity produced by contraction in these muscle fibers of the external intercostals. As has been noted, most of this expansion is sidewise, in consequence of the processes just considered. But since the ribs follow, from the spinal column downwards, such a radical slope in their forward direction, any raise must inevitably also produce a considerable front-to-back (anterior-posterior) internal spread of the chest cavity. Where we include movements of the diaphragm, whose function regularly coördinates herewith, an enlargement in three directions is thus provided: (1) *lateral*, *i.e.* out at the sides, (2) *anterior-posterior*, *i.e.* out in front, (3) *vertical*, *i.e.* down into the abdomen.

Posture and Distention. Of course we can also do much to facilitate this raising, by the position in which we place the spinal column. For, as we have noted, the back ends of each pair of ribs are attached to a separate dorsal segment of the vertebral column. Since the spine at that point normally curves upward like an elongated narrowed S, when the individual " slumps down " the inevitable result is to flatten the chest cavity by dropping the whole front mass of the ribs. This dropping also very radically interferes with the freedom of movement both in the intercostals and the diaphragm spoken of below. On the other hand, by " straightening up," throwing the shoulders back, and poising the head so as not to allow it to fall forward, we facilitate the expansion of the lungs.

The **diaphragm** (see Fig. 173), which is located inside this thoracic or chest cavity, provides for the up-and-down variation in pressure against the lungs. It is dome-shaped or convex in form, like an umbrella, and thus forms a musculo-fibrous partition between the thoracic and abdominal cavity. Its lower edges are attached around the full circumference of the chest: in front from the *xiphoid* process (or lower tip) of the sternum (see Fig. 180); thence around from the lower boundary of the *six bottom ribs* (see Fig. 180); then from the arches of *lumbar fascia;* and finally, by two vertical bundles called *crura*, at the sides of the *lumbar vertebræ* (Fig. 181). The muscular portion at the top is inserted in these fibers, which converge towards the center. The whole is highly arched and supports the lungs on either side with the heart in the center. The right portion is somewhat higher than the left; for the left lung is longer than the right, though the right is broader, larger, and heavier.



1 **Depressor alæ nasi muscle (outer part)**
M. nasalis (pars alaris)

2 **Depressor alæ nasi muscle (inner part)**
M. depressor septi

3 **Buccinator muscle**

4 **Depressor labii inferioris or quadratus menti muscle**

5 **Transversus menti muscle (var.)**
M. transversus menti (var.)

6 **Levator labii inferioris or levator menti muscle**
M. mentalis

7 **Incisivus superior muscle**
M. incisivus labii superioris

8 **Levator anguli oris muscle, or musculus caninus**
M. caninus

9 **Orbicularis oris muscle**

10 **Buccinator muscle**

9 **Orbicularis oris muscle**

3

4

11 **Mucous membrane of the mouth**
Tunica mucosa oris

12 **Incisivus inferior muscle**
M. incisivus labii inferioris

FIG. 176. — ORBICULAR ORIS MUSCLE, AND ITS RELATION TO THE ADJOINING MUSCLES; SEEN FROM BEHIND.

It is this difference which provides for the inclination of the heart to the left side.

How the Diaphragm Works. The chest cavity is much enlarged in a vertical direction when the muscular portion of the diaphragm contracts, in which course the central tendon is pulled down (Fig. 181). In either so-called chest or abdominal breathing the diaphragm seems to play a part. And so if it were only for this reason alone, the diaphragm might be called the most important of the respiratory muscles; but it will be noted its movements are those of inflation rather than deflation.

In **normal breathing** its movement is just sufficient to provide the short breaths which respiration calls for in order to keep a proper balance between the oxygen and carbon dioxide required by the blood. To this extent, the respiratory movements are involuntary; for while we may intentionally arrest breathing for a certain time, when the carbon dioxide has been increased enough, it becomes impossible for an individual to " hold his breath " any longer; and though we may start by taking deep, rapid breaths, in time the blood becomes so rich in oxygen as to almost automatically slow down the process. This condition is known as *physiological apnea.*

Breathing Rate. The normal rate of respiration for an adult is around fourteen to twenty per minute. But emotion, pain, a dash of cold water, suffocation, any increased general bodily muscular effort of the body, etc. cause an immediate change in the rate and deepness with which we breathe. Posture does likewise. The greater the degree of relaxation the slower the rate. Increase of temperature quickens the rate. As people get stouter the rate also accelerates and they develop a notorious tendency to " get out of breath." The baby's rate is as high as from forty-four to sixty-eight but it decreases to around twenty-six at the age of five. In other words, respiration is rhythmical, in its automatic aspects, but the rhythm changes with age and conditions. And it follows that the artistic singer, as well as the trained actor and speaker, should look well to a proper control of as many factors therein as can be modified to advantage.

Breathing in Singing. Filling of the lungs may be a more or less conscious process in speech and song. The necessity for the proper balance of carbon dioxide and oxygen is provided for in a compensation between the rapidity with which breaths are renewed and the length of time during

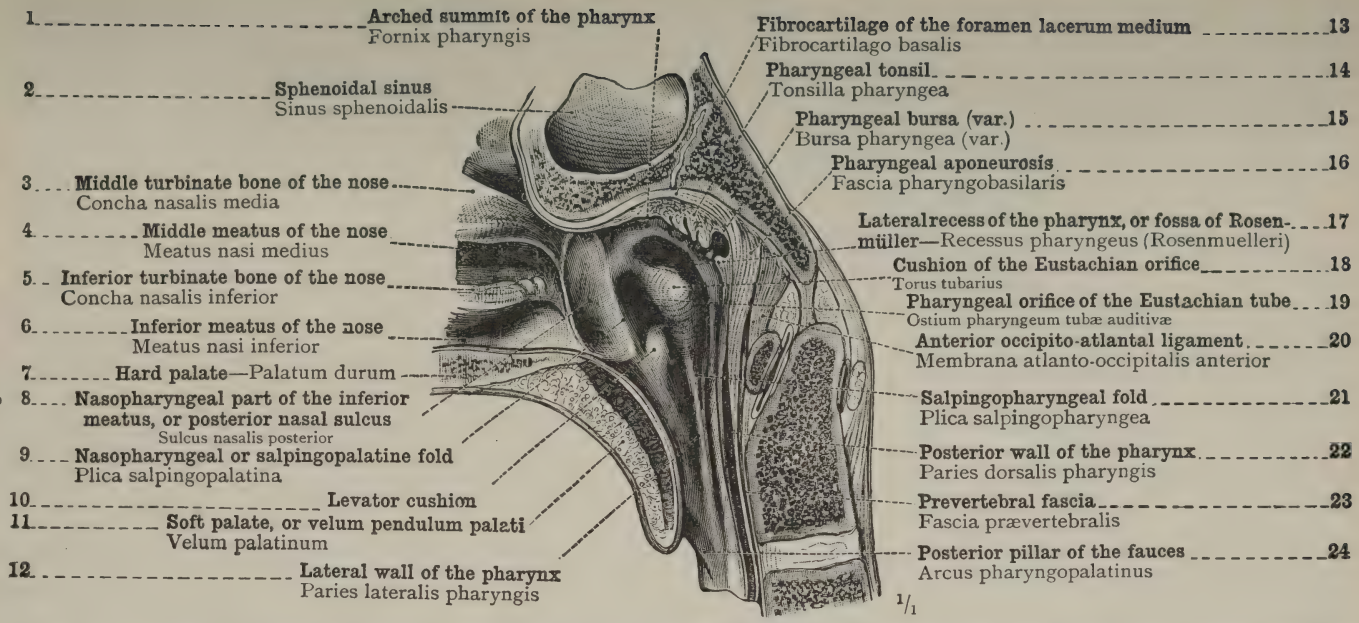

1 Arched summit of the pharynx
Fornix pharyngis
2 Sphenoidal sinus
Sinus sphenoidalis
3 Middle turbinate bone of the nose
Concha nasalis media
4 Middle meatus of the nose
Meatus nasi medius
5 Inferior turbinate bone of the nose
Concha nasalis inferior
6 Inferior meatus of the nose
Meatus nasi inferior
7 Hard palate—Palatum durum
8 Nasopharyngeal part of the inferior meatus, or posterior nasal sulcus
Sulcus nasalis posterior
9 Nasopharyngeal or salpingopalatine fold
Plica salpingopalatina
10 Levator cushion
11 Soft palate, or velum pendulum palati
Velum palatinum
12 Lateral wall of the pharynx
Paries lateralis pharyngis
13 Fibrocartilage of the foramen lacerum medium
Fibrocartilago basalis
14 Pharyngeal tonsil
Tonsilla pharyngea
15 Pharyngeal bursa (var.)
Bursa pharyngea (var.)
16 Pharyngeal aponeurosis
Fascia pharyngobasilaris
17 Lateral recess of the pharynx, or fossa of Rosenmüller—Recessus pharyngeus (Rosenmuelleri)
18 Cushion of the Eustachian orifice
Torus tubarius
19 Pharyngeal orifice of the Eustachian tube
Ostium pharyngeum tubæ auditivæ
20 Anterior occipito-atlantal ligament
Membrana atlanto-occipitalis anterior
21 Salpingopharyngeal fold
Plica salpingopharyngea
22 Posterior wall of the pharynx
Paries dorsalis pharyngis
23 Prevertebral fascia
Fascia prævertebralis
24 Posterior pillar of the fauces
Arcus pharyngopalatinus
1/1

FIG. 177.—PARS NASALIS PHARYNGIS, THE NASAL PART OF THE PHARYNX, NASOPHARYNX, OR POST-NASAL SPACE, AND ITS CONNECTION WITH THE NASAL FOSSÆ, IN MEDIAL SAGITTAL SECTION. VIEW OF THE RIGHT LATERAL WALL OF THE NASOPHARYNX, WITH THE PHARYNGEAL ORIFICE OF THE EUSTACHIAN TUBE. TONSILLA PHARYNGEA, THE PHARYNGEAL TONSIL: BURSA PHARYNGEA, THE PHARYNGEAL BURSA. SULCUS NASALIS POSTERIOR, THE NASOPHARYNGEAL PART OF THE INFERIOR MEATUS OF THE NOSE, OR POSTERIOR NASAL SULCUS, CORRESPONDING TO THE NASOPHARYNGEAL MEATUS; PLICA SALPINGOPALATINA, THE NASOPHARYNGEAL OR SALPINGOPALATINE FOLD; PLICA SALPINGOPHARYNGEA, THE SALPINGOPHARNGEAL FOLD.

which each filling is held. Where the balance is broken, the individual becomes ill at ease, and more or less automatically makes a change.

Out of Breath. As has been noted, the emotional situation may result in radical modifications. If the singer becomes excited and loses the poise so necessary to her finished artistry, oxidation takes place so rapidly that short quick breaths are almost forced. Then a prolonged or held breath such as is necessary to maintain a sustained tone becomes practically a physiological impossibility. The blood demands more oxygen; and we say the individual is "out of breath." Yet it will be seen that the individual did not actually fail to take in enough breath. The amount of air inhaled may be identical in two cases, but if the oxygen is rapidly exhausted in the one, then nature forces the taking of another breath long before it would be necessary in the normal process represented in the other.

Necessity for Poise. For this reason, cultivated confidence, and such poise as will enable one to fight down excitement and fear, are an absolute necessity to a well-trained vocal artist, or in a lesser degree to anyone who is called upon to stand and speak. Let us now turn to another chapter for a consideration of how breathing takes place in singing and speaking.

CHAPTER XVIII

BREATHING

"The chief condition for the production of articulate sounds is a current of air, modifications of which, produced at will, are perceived as sounds. Such modifications are, *e.g.* streaming through a large cavity or through a narrow slit, sudden interruption of the current or a sudden removal of some obstruction to the current, etc.

"Such a current of air is an accessory phenomenon in the process of respiration, in which the air is at regular intervals first drawn into the lungs and then driven out again. . . .

"The lungs are directly connected with the external air by the cavities of the pharynx (throat), the mouth, and the nose; and the current of air created during inspiration finds its way through these cavities into the windpipe, and so into the lungs; and in the same manner the current of air expelled from the lungs passes out again through these cavities. . . .

"It is clear why the expired current of air is most suitable for the production of sound. . . . The entering current of air must be produced by muscular activity, and can only with difficulty be drawn in slowly or for any length of time; the returning current (expiration), on the other hand . . . only requires to be regulated to form a continuous current of air of sufficient duration for the production of sound."

MEYER (1884).[1]

INHALATION

Breathing consists of two processes: *inhalation* and *exhalation.* Most of our physiological discussion has thus far been concerned with the first; **Inhalation.** The process of inhalation is complex. We have devoted most of our attention to the function of (1) the *external intercostals* in a consideration of lung function. This is principally because their operation is rather hard to visualize. We have also noted the process involved in the operation of (2) the *diaphragm,* which we indicated as the most important of the breathing muscles.

But there are **other muscles** involved in the process of inhalation, some of which must relax, while others must remain tense. Consider, for example, (3) the various *abdominal muscles* (Figs. 173 and 184) which must make room for the downward push of the diaphragm.

[1] Meyer, G. H. V. *The Organs of Speech,* Appleton, 1884, pp. 5, 9, 16.

Chest. Then there are those which run across the exterior of the chest, like the (4) *pectoralis minor* (#14 Fig. 184), pulling from the front shoulder blade (*scapula*) to the surface of the third, fourth, and fifth ribs near the cartilages. Besides there is (5) the *sternocleidomastoid* (#5 Fig. 182 and #26 Fig. 183, also #1 Fig. 183) on each side, attached to the skull right behind the ear, and to the upper part of the chest bone (sternum). When both of these act together they pull the head forward, but if the back muscles hold it up they serve to raise the whole framework of the chest; and as has been noted, this process operates to enlarge the whole interior chest cavity, but especially the lower part. This can be seen by reference to Fig. 180, showing the normal downward slope of the ribs, #5 Fig. 182, and #26 Fig. 183. The preceding number (4) above likewise so functions.

Along the **spine** there are others such as (6) the *levatores costarum*, twelve small fan-like strips fastening from the side projections of the vertebra in the back to the rib below it, (7) the *scaleni* leading from the side projections of the neck vertebra to the upper first and second ribs, and (8) the *serratus posticus superior*, attaching likewise from the lower neck vertebræ to the upper borders of the top second, third, fourth, and fifth ribs.

Others. Additional muscles in the trunk, larynx, pharynx, and face are also involved. But none of these from number (6) down are so important as the preceding, though their function is mostly manifest in forced inspiration of the type most likely to be used in singing and elocution.

How the Lungs Fill. It follows that the amount of air which can be taken into the lungs is directly dependent on the extent to which the cavity containing the lungs can be distended. The pressure in the air cells themselves is practically constant since they communicate with the outside by way of non-collapsible tubes; but any constrictions in the vocal passage, such as those necessary in speech and song, will of course result in pressure variation in the cells, even when the muscular pressure is kept constant.

Outside Air Pressure Responsible. It is of course the outside air pressure which in the final analysis causes the inrush. For since the pressure must be kept equalized, if the chest cavity is enlarged by lowering the diaphragm and elevating the ribs, the equivalent of a vacuum in the space around the lungs is created; hence the air immediately rushes

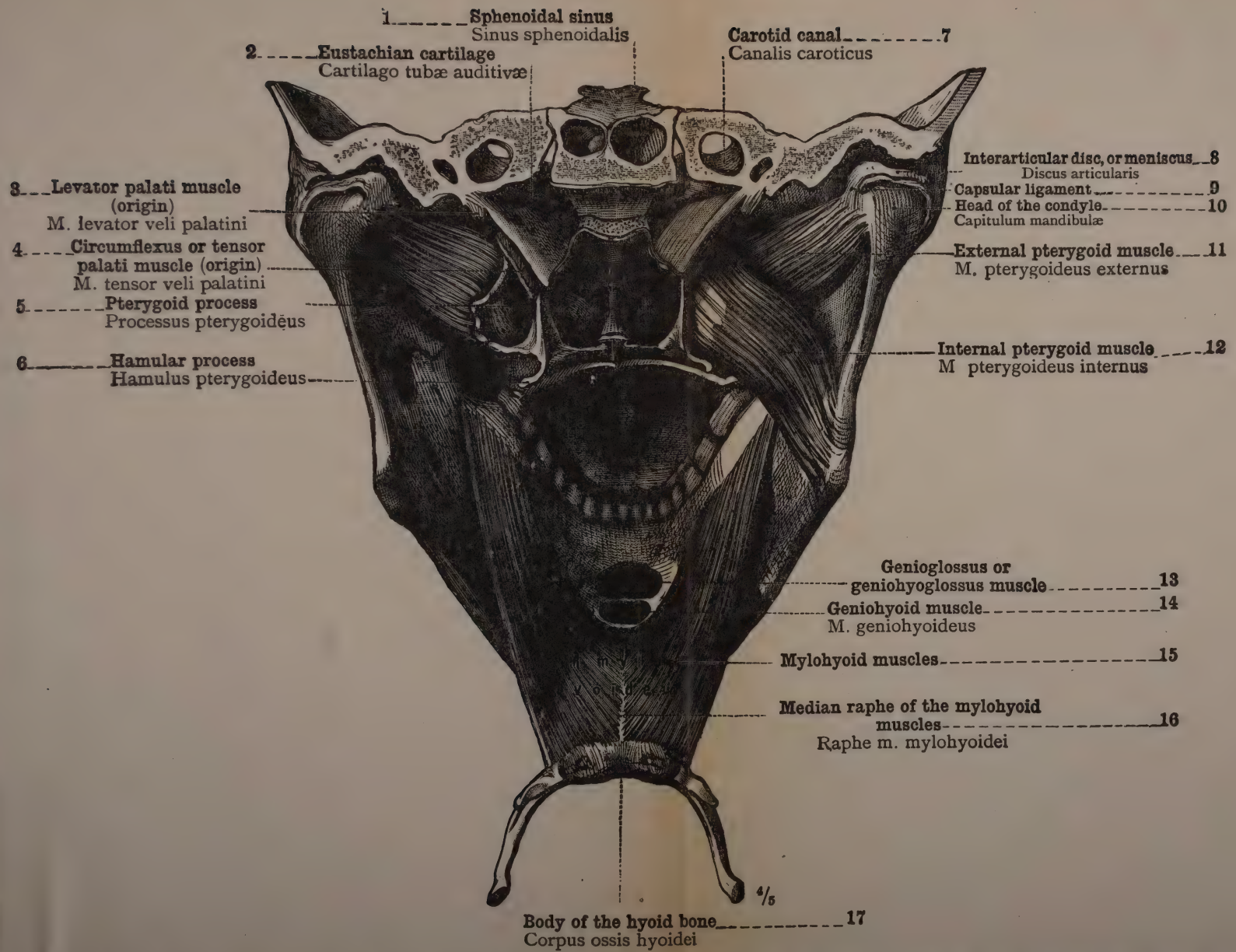


FIG. 178. — M. MYLOHYOIDEUS, THE MYLOHYOID MUSCLE, THE RIGHT AND LEFT MUSCLES FORMING THE DIAPHRAGMA ORIS, SEEN FROM ABOVE AND BEHIND. THE PTERYGOID MUSCLES, EXTERNAL AND INTERNAL, ARE DISPLAYED BOTH INTACT ON THE RIGHT SIDE, WHILE ON THE LEFT SIDE THE INTERNAL PTERYGOID MUSCLE HAS BEEN REMOVED IN ORDER TO LAY BARE IN ITS WHOLE EXTENT THE POSTERIOR SURFACE OF THE EXTERNAL PTERYGOID MUSCLE.

into the cells and expands them until this space is filled. In other words, the process is one tantamount to suction created by a vacuum. This condition within the chest is spoken of as the *intrathoracic pressure.* It is of interest to note that if a puncture is so made as to provide an opening through the chest wall into the space between the two layers of the pleura, and air is allowed to penetrate the area between the lung and chest, then the lung immediately collapses. But if the puncture is again closed the air is absorbed and the lung gradually assumes its normal shape. That is to say, we have evidence here that the lungs themselves are not capable of causing either exhalation or inhalation — pressure or its opposite — which we may designate as the inrush. The whole process is one created by the operation of the diaphragm and of the abdominal and chest cavity muscles.

Exhalation

Exhalation. For the most part exhalation is but a process of relaxation in normal breathing. Owing to the pull of gravity and the construction of the chest framework, with its downward sloping ribs attached hinge-like at the back and cradled to a freely swinging sternum in the front, they drop of themselves, and when relaxed, press the air out of the lungs.

But when the **expiration is forced, as** it normally is **in speech and song,** actual muscular activity is regularly brought to play: (1) through the *internal intercostals*, whose exact function, as was above indicated, is debatable; but which, attached as they are from rib to rib as oblique fibers, would seem in general to serve as one of the most forcible means of contracting the chest cavity. Of course this refers merely to the costal function. They are aided by (2) the *transversus thoracis*, whose fibers pass from the sternum running upward and outward to the costal cartilages from the second to the sixth rib. Then there are undoubtedly others like (3) that part of the *sacrospinalis* (erector spinæ) called the *iliocostal* — one of the three columns of the muscle mass attached to the lower back part of the lowest spine (sacrum, lumbar, and thoracic vertebræ) and hip bone (iliac crest), thence up to the lower borders of the bottom six or seven ribs. Likewise there are (4) the *serratus posticus inferior*, running from the middle back (lower two thoracic and upper second or third lumbar) vertebræ to the inferior borders of the lower four ribs; and perhaps (5) the *quadratus lumborum*, a square, flat muscle lying

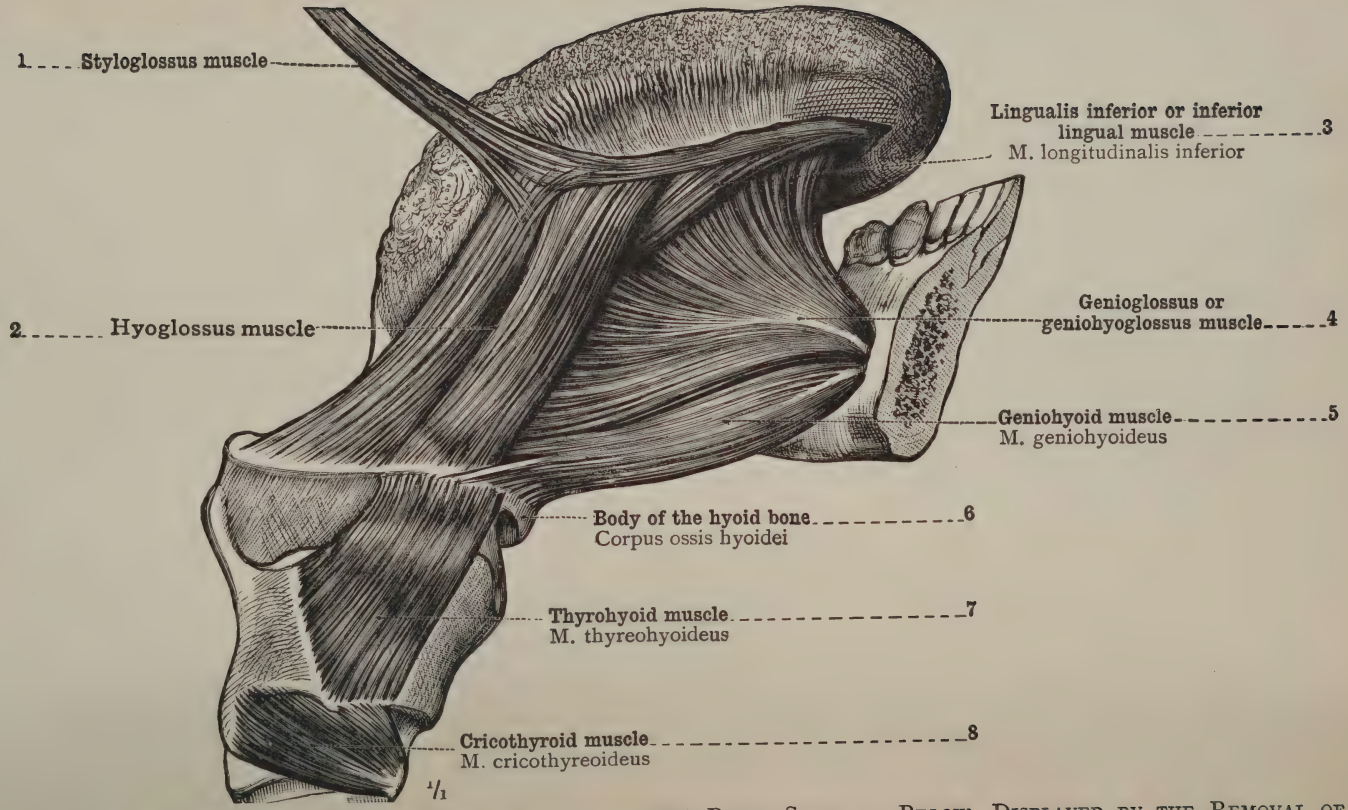


FIG. 179. — THE MUSCLES OF THE TONGUE SEEN FROM THE RIGHT SIDE AND BELOW, DISPLAYED BY THE REMOVAL OF THE HYOGLOSSUS MUSCLE: M. LONGITUDINALIS INFERIOR, THE INFERIOR LINGUAL MUSCLE; M. TRANSVERSUS (VEL. TRANSVERSALIS) LINGUÆ, THE TRANSVERSE MUSCLE OF THE TONGUE, AND ITS RELATION TO THE GENIOHYOGLOSSUS MUSCLE; THE CHONDROGLOSSUS MUSCLE.

toward the back part of the abdominal wall, running from the top hip bone (iliac crest) to the lower border of the twelfth rib and certain vertebræ. Any or all of these may possibly be involved in chest function.

The (6) *diaphragm* itself does not function directly in expiration so much as indirectly by means of relaxation whereby it permits of pressure being otherwise brought to bear through contraction of the muscular walls of the abdomen. The principal *abdominal muscles* involved are (7) the *external oblique* (#9 Fig. 184), (8) the *internal oblique* (#21 Fig. 184), (9) the *rectus* (#20 Fig. 184), and (10) the *transversalis* running laterally across the latter. Careful observation of the first above-mentioned fact is of more than usual importance. For too many writers who have essayed to consider the subject of breathing in speech and song have been prone to speak of the diaphragm itself as the functioning muscle brought to bear in creating loudness and other variations in the voice tone. **Since the abdominal muscles are the ones so powerfully involved in producing breath pressure for singing, the necessity for developing their tonicity, power, and control would seem to be very evident. Hence, too much stress cannot be laid on erect carriage, care of digestion, and the elimination of colonic gas, reduction of fatty abdominal flabbiness, etc.**

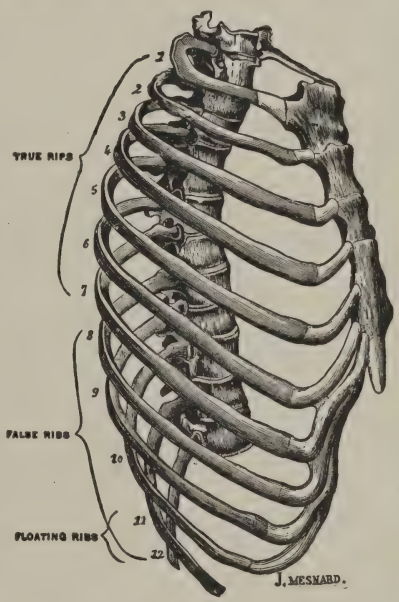


FIG. 180

The **capacity of the lungs** or the amount of breath which can be made available for speech and song varies, of course, considerably. For by practice, it is possible to increase the capacity of the lungs a great deal. Of course for such purposes we must needs consider the forced processes.

Careful measurements have shown that the amount of air which the average individual can expel by forcible processes after a consciously taken *deep breath* will vary from around 3500 to 4500 cc. (7 to 8 pts., figuring 568 cc. to a pint).

In normal breathing, the amount of air which flows in and out of the lungs with the vocal cords wide open will average around 500 cc. (1 pt.) for the adult. This is called the *tidal air.*

A forced inspiration after reaching this point will usually add something like an additional 1600 cc. (3 pts.). This is called *complemental air.*

About the same amount of air (1600 cc.) can usually be forced out of the lungs after the completion of the normal quiet expiration. This is often designated the *supplemental air.*

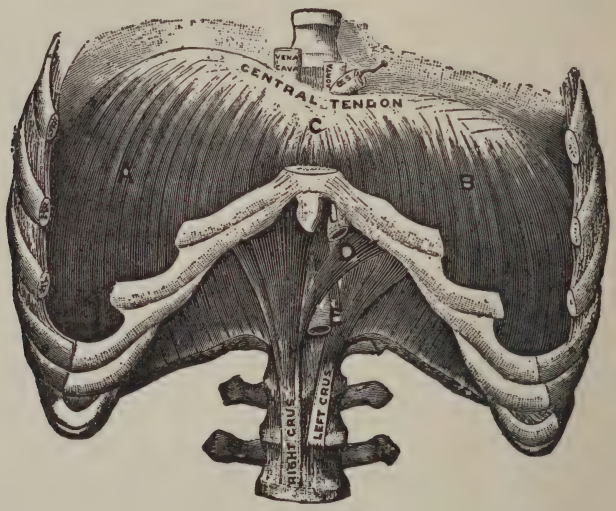


FIG. 181

But even after one has apparently expelled all the air in the lungs, there remains a substantial amount which has been estimated from tests on cadavers to be around 1000 cc. (2 pts.). This is designated as the *residual air.*

From the above it will be seen that the lungs keep present, normally, the 1000 cc. of this residual air, plus the 1600 cc. of supplemental air (or that which one can forcibly expel after completing a quiet expiration). This is called the *reserve air.*

Air a Singer Uses. It is this 2600 cc. (5 pts.) of reserve air, plus at times the 500 cc. (1 pt.) of tidal air, which we make use of in normal quiet speech. For such purposes radical variations in loudness are not demanded. But conditions change where one talks to an audience. It

follows that they do likewise for the singer. Then we need the maximum amount of air which can be comfortably obtained. But even then the full 3500–4500 cc. (7–8 pints or 1 gallon) are not usable.

Trained Breathing. We say the singer needs the maximum amount of air which can be comfortably obtained, for no artist would resort to the grotesque. The artist strives to make his or her singing as unconsciously easy and natural as possible. Of course this does not mean that the beginning muscular processes necessary to correct breathing in the singer are to be unconscious or felt as easy. Any psychologist or other scientist conversant with the human mechanism would designate such an assumption as a fallacy. It is unquestionably true that the teacher will call for the breaking of many old habits and the forming of new ones in their place. And any new voluntary motor act, such as that involved in the forced breathing required for the process of singing, must of course be consciously done; and in its initial stages this must inevitably be felt as the opposite of easy and natural.

Total Volume of Air not All. In order to provide conditions which will make this process of forced breathing as easy as possible, especially for the student who is learning, we must remember that the total volume of air at one's disposal is not the only factor involved in producing an "out of breath" sensation. The balance maintained between the carbon dioxide (suffocating element) and oxygen present in the lungs is, if anything, of even greater importance.

Emotional Interference and How to Overcome It. We noted that fear, anger, anxiety, or any of those emotions manifest in one lacking proper "poise," all operate to put one "out of breath" as quickly as any other one thing. This is because of the oxidation resulting therefrom, with its overload of suffocating carbon dioxide. One of the best ways to get rid of an obsession of this kind is to turn the attention to something else. As what is needed is "ample breath" such an individual might perhaps well turn his attention to conscious long sweeping rhythmical breaths; and in so doing, forget everything and everybody else around for the moment until the interfering disturbance is banished.

Other Interferences. Of course pain and all other like irritations, such as binding clothes, disturbing colors and noises, etc., etc., operate in much the same manner and for this reason should be eliminated just as much as possible. Since the balance of oxygen is essential, a close stuffy

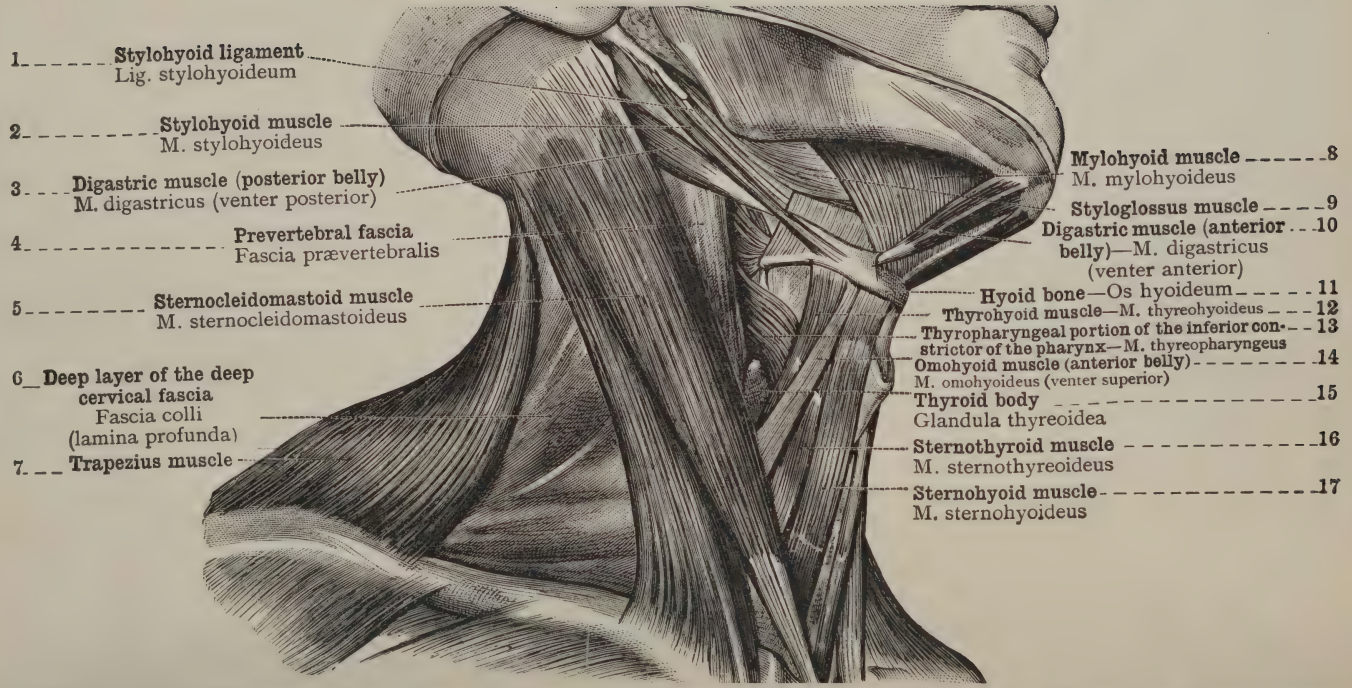


FIG. 182. — THE MUSCLES OF THE FRONT OF THE NECK, SHOWN ON THE RIGHT SIDE OF THE BODY. M. STERNOCLEIDOMASTOIDEUS, STERNOCLEIDOMASTOID MUSCLE; M. DIGASTRICUS, DIGASTRIC MUSCLE; THE RELATIONS OF THE LATTER TO THE STYLOHYOID AND MYLOHYOID MUSCLES. PORTIONS OF THE MUSCLES ARISING FROM THE STYLOID PROCESS; OF THE LOWER MUSCLES OF THE TONGUE, AND OF THE TRAPEZIUS MUSCLE ARE DISPLAYED.

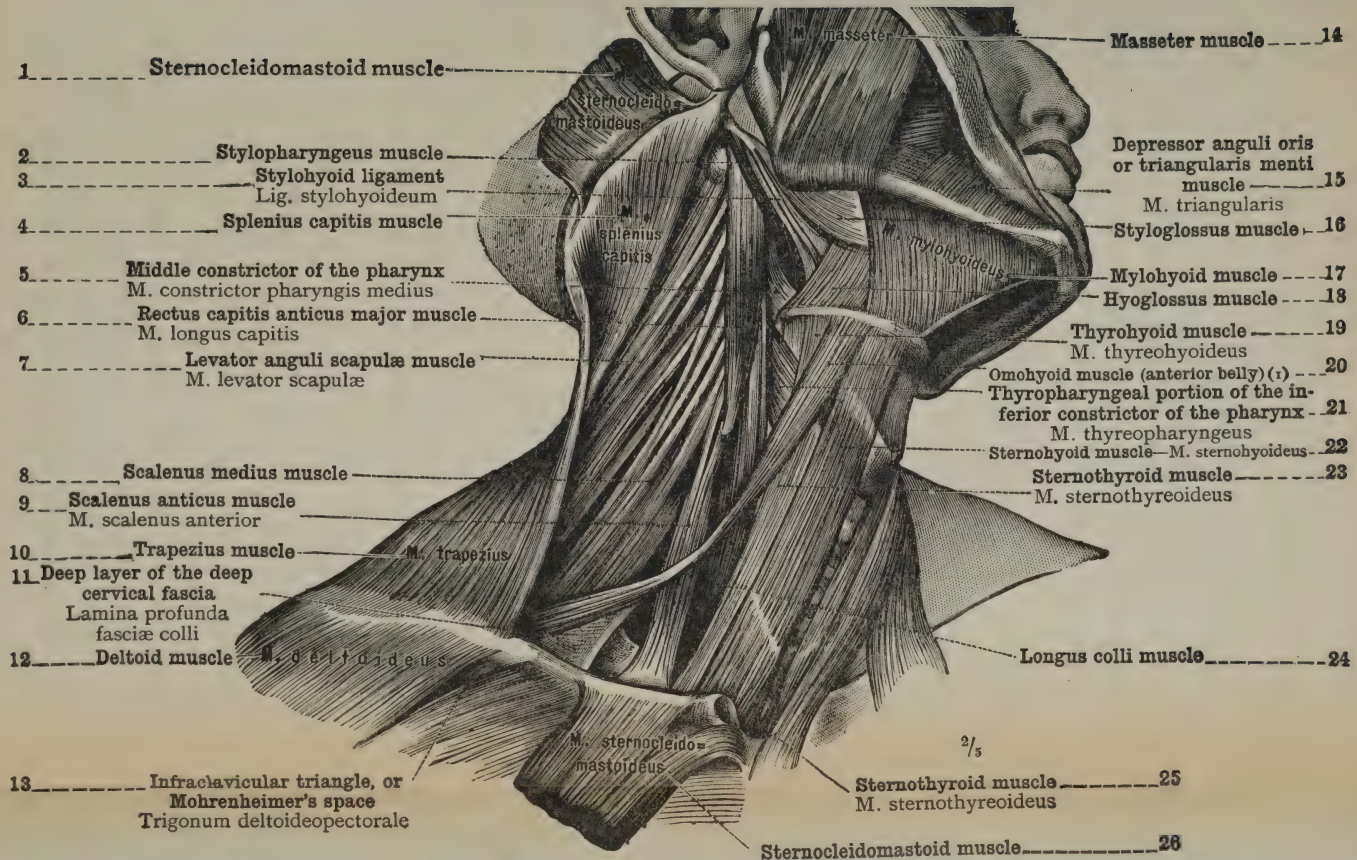


FIG. 183. — THE MUSCLES OF THE NECK, DISPLAYED ON THE RIGHT SIDE, THE STERNOCLEIDOMASTOID, DIGASTRIC, AND STYLOHYOID MUSCLES, STERNOHYOID, STERNOTHYROID, THYROHYOID, AND OMOHYOID. THE MYLOHYOID MUSCLE, THE ANTERIOR AND MIDDLE SCALENE MUSCLES, AND THE LEVATOR ANGULI SCAPULÆ; PORTIONS OF THE MUSCLES OF THE FACE, AND OF THE DEEP LATERAL AND PREVERTEBAL MUSCLES OF THE NECK.

room must inevitably create " shortness of breath." This goes without saying. Hence the necessity for plenty of fresh air.

Types of Breathing. Of the types of breathing which should be advocated little can be said here. This is not because one is no better than the other; but simply because the author has no new scientific facts to offer by way of contribution, and the question is one of these more or less moot ones which is still debated back and forth as it has been for generations now.

Summary Thereof. We may note six basic types of breathing. **First,** there is the *superior costal* or upper chest type, in which the whole rib framework is pulled upward with consequent expansion of the upper lung capacity.

But as has been noted, the chest or thorax is susceptible of providing a **second** type of expansion, the *inferior costal*, in which the lower ribs when they are raised are also made to spread out sidewise. These two types may be independently used or they may well function together.

Then there is a **third,** the *inferior costal abdominal*, in which the diaphragm is pulled downwards, accompanied by at least a partial movement of the lower ribs (the second type above). The abdomen bulges outward first, and as the breath taken becomes deeper, there then follows a more or less greater distention in the lower thorax.

Of course it is possible to take a **fourth** or *purely abdominal* type of breath in which the chest framework is left relaxed and hanging down. But then the quantity of air which can be inhaled is much more limited; and since both the inspiratory and expiratory processes are decidedly muscular, this type is quite as tiring as any of the rest and much more so than either the *first* or *second* in which the expiration is primarily a movement of relaxation.

A **fifth,** the *maximal expansion* type, may be noted in which all the movements of the *first*, *second*, and *fourth* are carried out. This process permits the maximum amount of air to be used, since thereby the whole thoracic cavity may be distended to the limit. The chest rises, and thus the upper lungs are filled; the lower ribs spread outwards, and hence the maximum lateral and anterior-posterior distention of the lungs is provided; the diaphragm is pulled downward, and therefore the air pressure from the outside causes the inrush which forces the lungs to stretch out vertically or lengthwise as much as is possible on the deep-

est breaths. Since a maximum collapse is also forced, all the air which can be pressed out may be made use of. Hence *this process gives the individual the maximum usable volume of air.*

But the average untrained individual will probably find this one of the most tiring of the processes considered. Yet it is the one he is most likely to make use of if he is merely told to breathe deeply; and it is of course the one advocated by doctors and others who desire him to make a complete change of air in all the cells. If one considers the carbon dioxide-oxygen balance above referred to, it would logically seem to be the best, since even the air in the upper cells is kept constantly renewed. Of course there are other factors, some of which have been considered so objectionable as to outweigh this advantage. One is to be noted in the complexity of the act; another in the question as to whether it is more tiring than some other process which may be made almost as efficient; and again one must of necessity consider the possible smoothness and ease of muscular control. As one writer has said:

> "However abundant the supply of air may be . . . a jerky respiration makes it impossible to sustain or colour the phrase," . . .

The criticism expressed in this quotation cannot be answered and the other points raised cannot be properly weighed without the scientific investigation which, simple as it is, still remains to be done.

A **sixth,** the *fixed high-chest* method, has been rather vigorously advocated, principally because of the plausibleness of the objection we have just been discussing. It calls for the elevation of the chest, thus keeping the upper part of the lungs filled and available as a reserve supply. (However, it will be remembered that these cells are then probably loaded with what is mostly carbon dioxide, which would make the contents of doubtful value to the singer after the position had been held any great length of time.) In this type of breathing the control of the bellows is thus left primarily to the function of the lower ribs and the diaphragm; and the gross movements of the chest framework as a whole are then eliminated.

Many modifications of both this latter, and the other processes considered have been advocated. Dr. Holbrook Curtis credits Jean de Reszke with the view that

> "the abdominal wall should be retracted in its inferior portion only — *i.e.*, as high as the belt — the pit of the stomach being allowed to follow the general excursion of the diaphragm and lower ribs;"

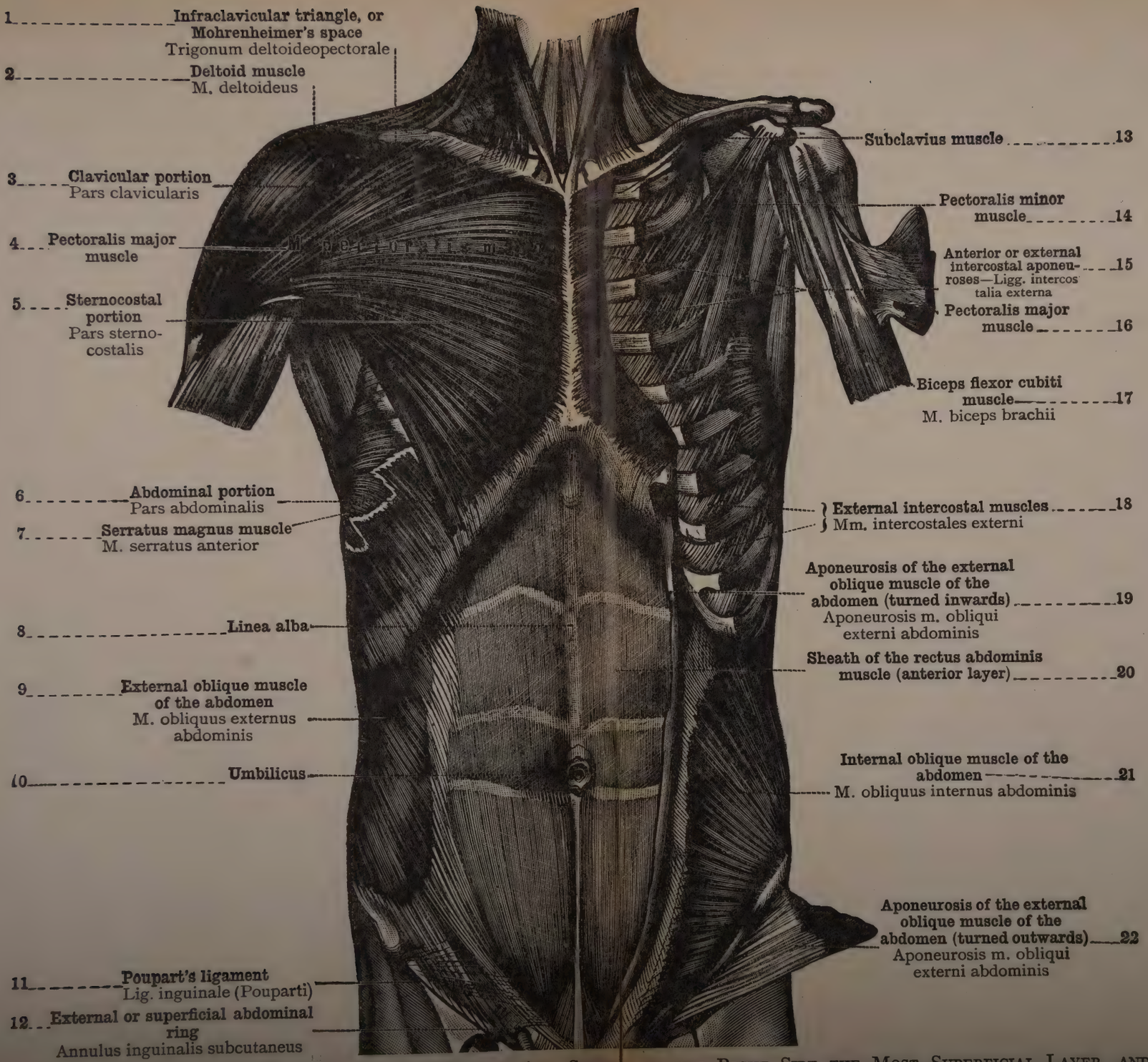

1 Infraclavicular triangle, or Mohrenheimer's space
Trigonum deltoideopectorale
2 Deltoid muscle
M. deltoideus
3 Clavicular portion
Pars clavicularis
4 Pectoralis major muscle
5 Sternocostal portion
Pars sterno-costalis
6 Abdominal portion
Pars abdominalis
7 Serratus magnus muscle
M. serratus anterior
8 Linea alba
9 External oblique muscle of the abdomen
M. obliquus externus abdominis
10 Umbilicus
11 Poupart's ligament
Lig. inguinale (Pouparti)
12 External or superficial abdominal ring
Annulus inguinalis subcutaneus
13 Subclavius muscle
14 Pectoralis minor muscle
15 Anterior or external intercostal aponeuroses—Ligg. intercostalia externa
16 Pectoralis major muscle
17 Biceps flexor cubiti muscle
M. biceps brachii
18 External intercostal muscles
Mm. intercostales externi
19 Aponeurosis of the external oblique muscle of the abdomen (turned inwards)
Aponeurosis m. obliqui externi abdominis
20 Sheath of the rectus abdominis muscle (anterior layer)
21 Internal oblique muscle of the abdomen
M. obliquus internus abdominis
22 Aponeurosis of the external oblique muscle of the abdomen (turned outwards)
Aponeurosis m. obliqui externi abdominis

FIG. 184. — THE THORACIC AND ABDOMINAL MUSCLES ARE SHOWN, ON THE RIGHT SIDE THE MOST SUPERFICIAL LAYER, AND ON THE LEFT SIDE THE LAYER IMMEDIATELY BENEATH THIS PECTORALIS MAJOR AND PECTORALIS MINOR MUSCLES; SUBCLAVIUS MUSCLE; EXTERNAL AND INTERNAL OBLIQUE MUSCLES OF THE ABDOMEN.

and speaks of Pol Plançon's :

"perfectly immobile chest in difficult phrasing being a salient feature of his style;"

but he says

"in Melba, Eames, and Nordica we see types of 'high-chest' breathing."

Conclusion. We can do no better than cite the following from Dr. Vorhees [2] as among the principles submitted at the N. Y. State Music Teachers' Association Convention, June, 1915, by the Committee on Standards :

"Perfect control of the breath means:

(*a*) Ability to fill the lungs to their capacity either quickly or slowly;
(*b*) Ability to breathe out as quickly or as slowly as occasion demands;
(*c*) Ability to suspend inspiration . . . and to resume the process at will without having lost any of the already inspired breath;
(*d*) Ability to exhale under the same restrictions;
(*e*) Ability to sing and to sustain the voice on an ordinary breath;
(*f*) Ability to breathe quietly as often as text and phrase permit;
(*g*) Ability to breathe so that the fullest inspiration brings no fatigue;
(*h*) Ability so to economize the breath that the reserve is never exhausted;
(*i*) Ability to breathe so naturally, so unobtrusively, that neither breath nor lack of breath is ever suggested to the listener."

And perhaps one other at least may be added :

(*j*) Ability so to breathe as not to interfere with the muscular processes involved in artistic phonation, but on the contrary, so as to aid these processes where possible.

With this, the author must drop the subject of breathing. He has tried to give it the consideration he felt scientific consistency demanded, and for that reason must leave the decision as to what method is to be used to the reader. And no doubt each one will prefer to make his decision for himself anyhow. It is to this end that the known facts have been cited, in order to aid such a person in reaching an intelligent decision, without being forced to base it on a blind acceptance of somebody else's theory.

[2] Vorhees, Dr. I. W. *Hygiene of the Voice*, Macmillan (1923), p. 196.

CHAPTER XIX

THE SOURCE OF VOICE — MECHANISM BUT VAGUELY UNDERSTOOD

"Appreciation of the physiologic phenomena of normal talking, as well as of certain disorders of speech, including stammering, dysphonia spastica, the peculiarly disturbed voices of the deafened and other defects, as well as of certain problems of the artistic employment of voice and speech, necessarily await advancement in the present knowledge of the function of the larynx in speech."

ELMER L. KENYON, M. D. (1927).[1]

Vocal Cord Function Still Vaguely Understood. We may as well initiate this chapter with the admission that the exact manner in which the vocal cords and larynx function still remains more or less a mystery to us. Numerous views are advanced, defended, and argued. And many stand in radical disagreement with each other. Do the vocal cords operate like the lips in blowing a trumpet — with a puff-producing function? Or do they vibrate like two rubber strips stretched across the balloon whistle? This is the old debate which has been going on at least since the time of Dodart and Ferrein — from the close of the 1600's to 1742. Do the two cords vibrate in phase? West [2] within the last two years has argued that they do not,[3] and that as one goes up the other descends; whereas Metzger has advanced the opposite viewpoint.[4]

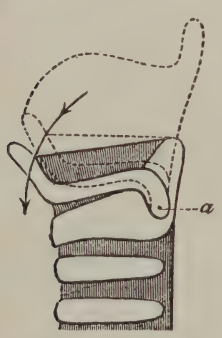


FIG. 185. — OLD THEORY OF GLOTTAL PITCH CHANGE.

Recently even some of those points long almost universally cited as proved facts have been very effectively contradicted. Such a one is

[1] Kenyon, Elmer L. "Relation of . . . Extrinsic Laryngeal Musculature . . . to Function of Vocal Cord," *Arch. Otolaryng.*, V (June, 1927), pp. 481–501.

[2] West, Robert. "The Nature of Vocal Sounds," *Quart. Jour. Speech*, Nov., 1926, p. 243.

[3] *Idem.* "Answer to Metzger," *ibid.*, Nov., 1928.

[4] Metzger, Wolfgang. In opposition to West, *Quart. Jour. Speech*, Feb., 1928. (More complete in) "Mode of Vibration of Vocal Cords," *Psych. Monog.* No. 176 (1928), pp. 81–159.

the basic fact involved in the question as to how pitch changes are accomplished by the vocal cords. If there is any one thing most scientists in the field as well as teachers of voice and speech thought they knew, it is that when the thyroid cartilage tipped forward and

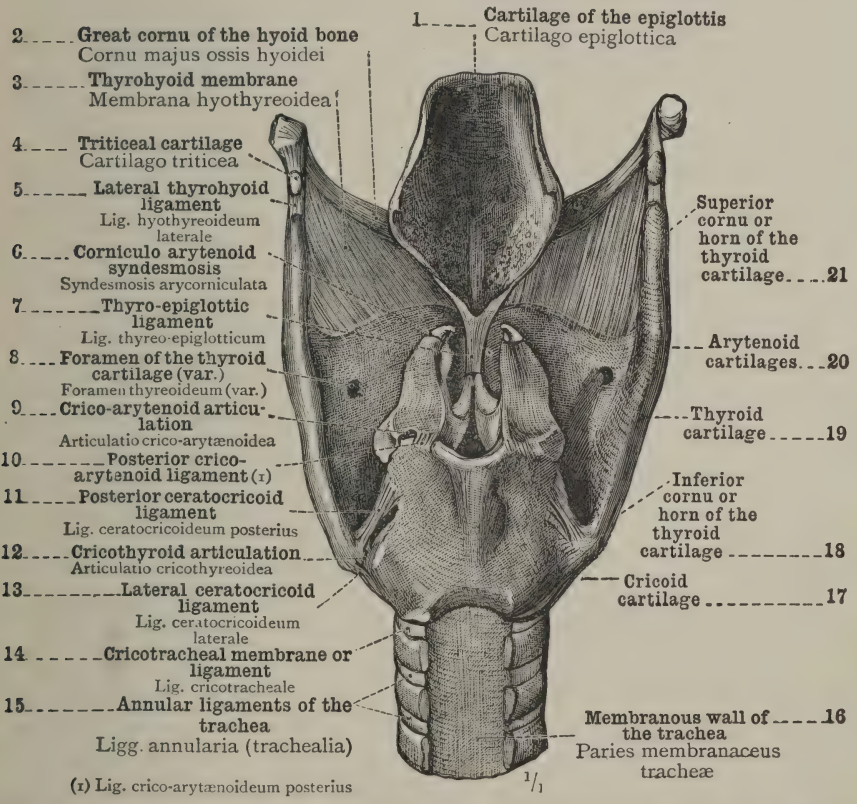


FIG. 186. — LIGAMENTS OF THE LARYNX, AND THE THYROHYOID MEMBRANE, SEEN FROM BEHIND.

downward, the pitch was raised. For since the front ends of the cords are fastened to the thyroid cartilage, and the back ends to the cricoid by way of the arytenoids supported thereon; and since the thyroid is attached at its lower back part hinge-like and thus cradled on the cricoid; it seemed plausible to assume that the cords would be stretched thereby and hence the pitch raised, when the anterior thyroid (Adam's

apple) was tipped downward. The diagram, Fig. 185, given by Meyer[5] portrays the classical idea:

> "To show that the depression, without the advancement, of the thyroid cartilage must cause the tension of the vocal cords."

Yet Kenyon, in the article from which the introductory quotation for this chapter was taken, reports on an investigation of the process through the use of external palpation of movement in these cartilages, which, he concludes:

> "reveals the error of this conception of stretching the vocal cords."

And the author after careful repetition of these experiments is willing to agree that in his own case a jump of a full octave from g (191 d.v./sec.) to g′ (383) shows a distinct rise of the thyroid and a hardly noticeable shift of the cricoid cartilage. From our standpoint but one qualification need be made: such radical and complex shifts take place in certain other ranges and on varying tonal qualities as to make assurance rather difficult. But in general, Kenyon's conclusions would seem to be entirely justified.

Polemical Assertions Unjustified. If we have to acknowledge conflicting viewpoints, and a lack of definitely proved and established facts pertaining to such basic questions as these, it is evident that the present study which proposes to be scientific may well disappoint the reader accustomed to polemical treatises on singing and speech. For we are not going to be able to make positive assertions as to just how the larynx and vocal mechanism function. Hence, we shall of necessity be limited, for the most part, to a consideration of the anatomy and physiology of the organs in question. These facts we shall attempt to present in such a way as to aid the reader in forming an intelligent conclusion of his own. So let us now look at these structures.

[5] Meyer, V. *The Organs of Speech*, Appleton, New York, 1884, p. 44.

CHAPTER XX

SPEECH CAVITIES — ANATOMICAL ORIENTATION

"Speech consists of variously modified emissions of breath. The first modifying agent is the glottis, or aperture of the wind-pipe; in passing through which, the breath acquires a rustling, vibratory, or sonorous quality, in proportion to the degree of tension and approximation of the vocal cords — the edges of the glottis. . . .

"The breath, glottally modified in either of these ways may be farther modified in its passage through the mouth, by the shape and arrangement of the plastic organs of articulation — the soft palate, the tongue, and the lips."

MELVILLE BELL (1900).[1]

The *larynx*, which contains the vocal cords (**glottal lips**), is mounted on and is but a part of the *trachea* (Fig. 174). This latter is the air-conducting tube leading from the *lungs* (bellows) by way of the *bronchi*. The first boundary may therefore be considered to be that represented by the vocal cords (also called *glottal wedges*); for they serve to separate distinctly the more or less "fixed-characteristic-tone" *lungs* and *conducting tube cavities* below from the "*variable resonators*" above. They also serve as the tone actuator when stimulated by the air pressure from beneath. In this sense the glottal lips correspond to the radio frequency generator in a broadcasting station; and the variable resonators above have heretofore been assumed to perform the function of the broadcasting modulators. But herein we have repeatedly pointed out manners in which the vocal lips serve, themselves, as modulators — in other words we have indicated that a large part of that which we call tonal quality in differences of both vowel and voice is traceable to a function of the vocal cords themselves. This chapter will repeatedly recur to a detailed consideration of this question. Hence we need here but warn that the so-called "variable resonators" are not alone responsible for what the singer calls "resonance." Yet it is wise to mark off the boundary just mentioned.

The **hyoid bone** (see #2 Fig. 186, #2 Fig. 187, #11 Fig. 182, and #7 Fig. 188) may be considered to represent another such boundary. For the *larynx* (see #10 and 11 Fig. 190), which we popularly designate as the

[1] Bell, A. Melville. *Principles of Speech*, Volta Bureau, Washington, D. C., 1900, 5th ed., pp. 1 and 2.

Adam's apple, is hung on to it. So functionally the hyoid cannot but be treated as a part of the larynx, in spite of all some may have said to the contrary. Hence it forms a convenient line of demarcation between the laryngeal and pharyngeal cavities immediately superior to the same.

Of course some may prefer to consider the approximation between (cf. #9 and 28 Fig. 190) the **cartilages of Wrisberg** (lying on top and towards the back of the larynx, see #6 Fig. 189, #7 Fig. 191), and the *pulvinar* or **cushion of the epiglottis** (see #2 Fig. 192, and #1 Fig. 189), as

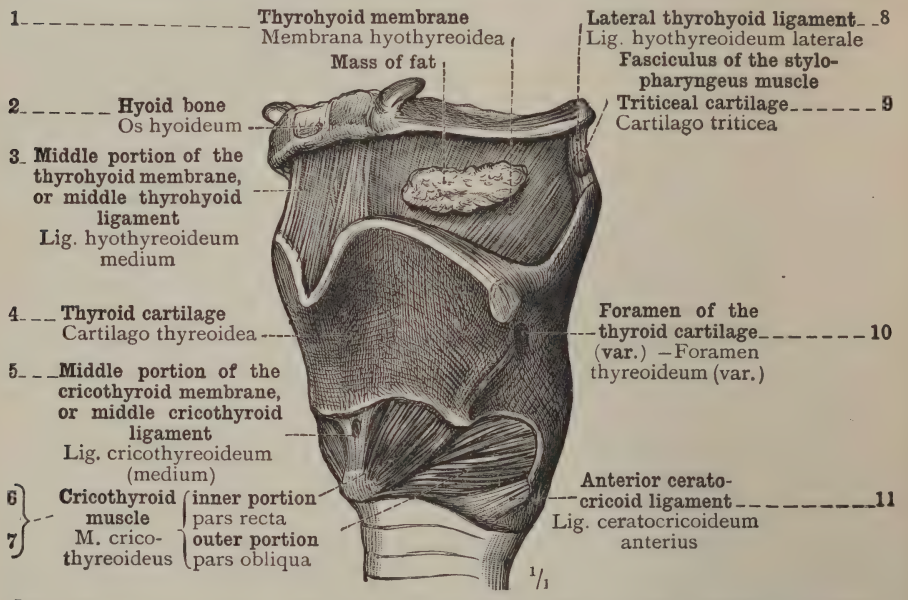


FIG. 187. — THE LARYNX WITH THE THYROHYOID MEMBRANE AND THE CIRCOTHYROID MUSCLE, SEEN OBLIQUELY FROM THE LEFT SIDE AND BEFORE.

marking a better boundary line; for these two operating together may all but completely close the opening between the larynx and pharynx.

Those who do may probably prefer to carry the fine distinction farther, and likewise take cognizance of the constriction made possible through the operation of the **false cords** (see #4 Fig. 192, cf. Fig. 191) or *ventricular bands* — especially in view of the observation reported herein showing them as regularly opening and closing, and performing a speech and voice function which is quite as vital as that of any other organs in question.

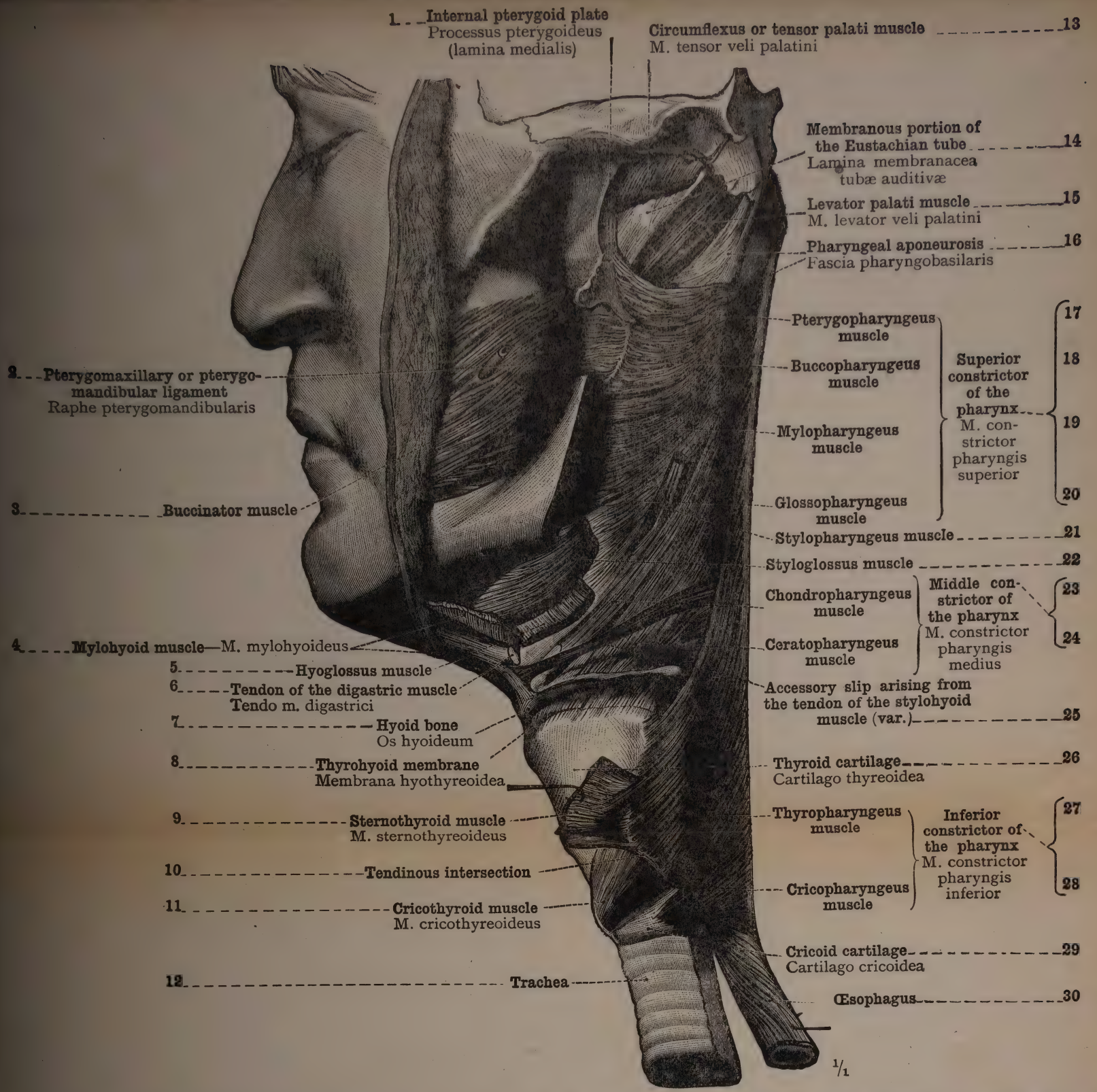


FIG. 188. — OUTER MUSCULAR LAYER OF THE PHARYNX, LAID BARE ON THE LEFT SIDE, BY THE REMOVAL OF THE RAMUS OF THE INFERIOR MAXILLARY BONE, THE MUSCLES ARISING FROM THE STYLOID PROCESS, THE POSTERIOR BELLY OF THE DIGASTRIC MUSCLE, AND THE MYLOHYOID MUSCLE: MUSCULI CONSTRICTORES PHARYNGIS, THE THREE CONSTRICTORS OF THE PHARYNX, WITH THEIR VARIOUS SUBDIVISIONS. CONNECTION OF THE BUCCINATOR MUSCLE WITH THE SUPERIOR CONSTRICTOR OF THE PHARYNX BY MEANS OF THE PTERYGOMAXILLARY OR PTERYGOMANDIBULAR LIGAMENT.

Behind the *larynx* lies the **esophagus** (see #30 Fig. 188). This is the tube down which the food slides on its way to the stomach. It plays no part in the speech of normal individuals. These two may be said to bifurcate or assume identity as separate tubes in the neighborhood of the wall between them, formed by the *cricoid* and *arytenoid cartilages* (see #29

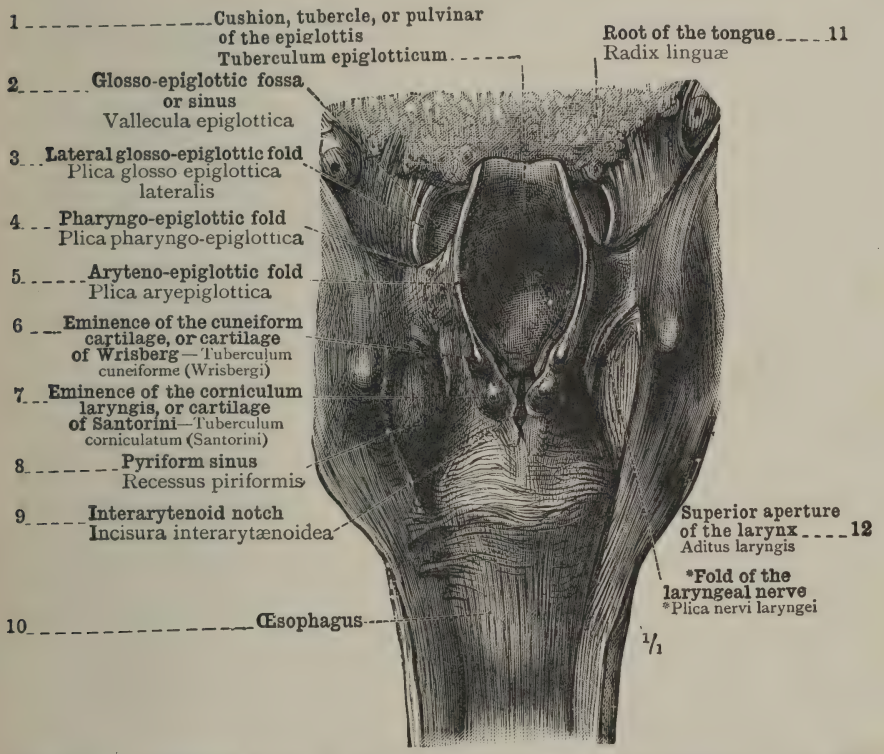

1 Cushion, tubercle, or pulvinar of the epiglottis
Tuberculum epiglotticum
Root of the tongue 11
Radix linguæ
2 Glosso-epiglottic fossa or sinus
Vallecula epiglottica
3 Lateral glosso-epiglottic fold
Plica glosso epiglottica lateralis
4 Pharyngo-epiglottic fold
Plica pharyngo-epiglottica
5 Aryteno-epiglottic fold
Plica aryepiglottica
6 Eminence of the cuneiform cartilage, or cartilage of Wrisberg — Tuberculum cuneiforme (Wrisbergi)
7 Eminence of the corniculum laryngis, or cartilage of Santorini — Tuberculum corniculatum (Santorini)
8 Pyriform sinus
Recessus piriformis
9 Interarytenoid notch
Incisura interarytænoidea
Superior aperture of the larynx 12
Aditus laryngis
*Fold of the laryngeal nerve
*Plica nervi laryngei
10 Œsophagus
1/1

FIG. 189. — ANTERIOR WALL OF THE LARYNGEAL PART OF THE PHARYNX WITH THE SUPERIOR APERTURE OF THE LARYNX.

Fig. 188, #16 Fig. 193, #29 Fig. 189, #9 Fig. 189, and #20 Fig. 186); or else somewhere around the upper point of the *superior cornu* of the *thyroid cartilage* (see #21 Fig. 186), which is best defined as resting about where the back end or prong of the hyoid bone lies.

Above this point the tubes become one for a space, being then designated the *oro-pharynx* (see #26 Fig. 190) (or **throat**). At the upper end of this latter the tube again divides and one part turns almost at right angles

into what we call the *buccal, oral* (see #3 Fig. 190), or *palatal cavity* (**mouth**) with an exit at the lips. (See #4 Fig. 190.) The back *tongue* (see #27 Fig. 190) and *palatine arches* (*velum*), together (see #23 and 24 Fig. 189), are capable of constricting so as to form another boundary — the barrier between the *buccal cavity* and *oro-pharynx.*

The other part of the throat tube leads up to the **nose** into what we call the *naso-pharynx.* This tube again turns forward to a final exit through the *nares* at the *nostrils.* The *velum* itself (see #24 Fig. 190), in its power of opening and closing its own aperture, forms the barrier between the *oro-* and *naso-pharynx.* In passing perhaps we might well remark that when we speak of the *pharynx* without these prefixes we refer to the throat proper (from #24 to 28 Fig. 190), or in other words to the perpendicular cavity which lies back of the palatine arches and extends from the larynx to the velum.

As will be seen (in Fig. 190), the *larynx* (#10), *pharynx* (#28 to 24), and *buccal cavities* (#3) are the ones subject to the most radical of those variations which might in any way be considered as vital in modifying tonal quality. In the **first** place, they may materially change the effect exercised by soft and varying degrees of hard or tense **surfaces.** In the **second** place, they can more materially alter their **size** and hence also the total **volume of air** (functioning as a resonator) which they contain. Thereby they change the characteristic pitch of the air-volume resonator which they represent. In the **third** place, they have **two openings** by which they may alter their cavity-tone pitch, whereas both the nasal and lung cavities have but one. The **second** and **third** reasons stand for their function as resonators. This is the capacity in which most writers have considered their influence to be most vital. It was this resonator effect which was supposed to create tonal quality, or in other words, so-called "voice placement," or what the singer called "good resonance." But this latter term "*resonance*" likewise implies *carrying power;* and this in turn implies *added loudness,* all of which assumes an influence on the part of these small, wet, and water-logged soft-walled cavities which laboratory experiment does not justify.

The **first** modifying effect mentioned above has been considered in detail herein for the first time. It may prove to be of even greater importance than the other two. And in so far as the influence of the hard surfaces is concerned, it shows the necessity for the consideration of a

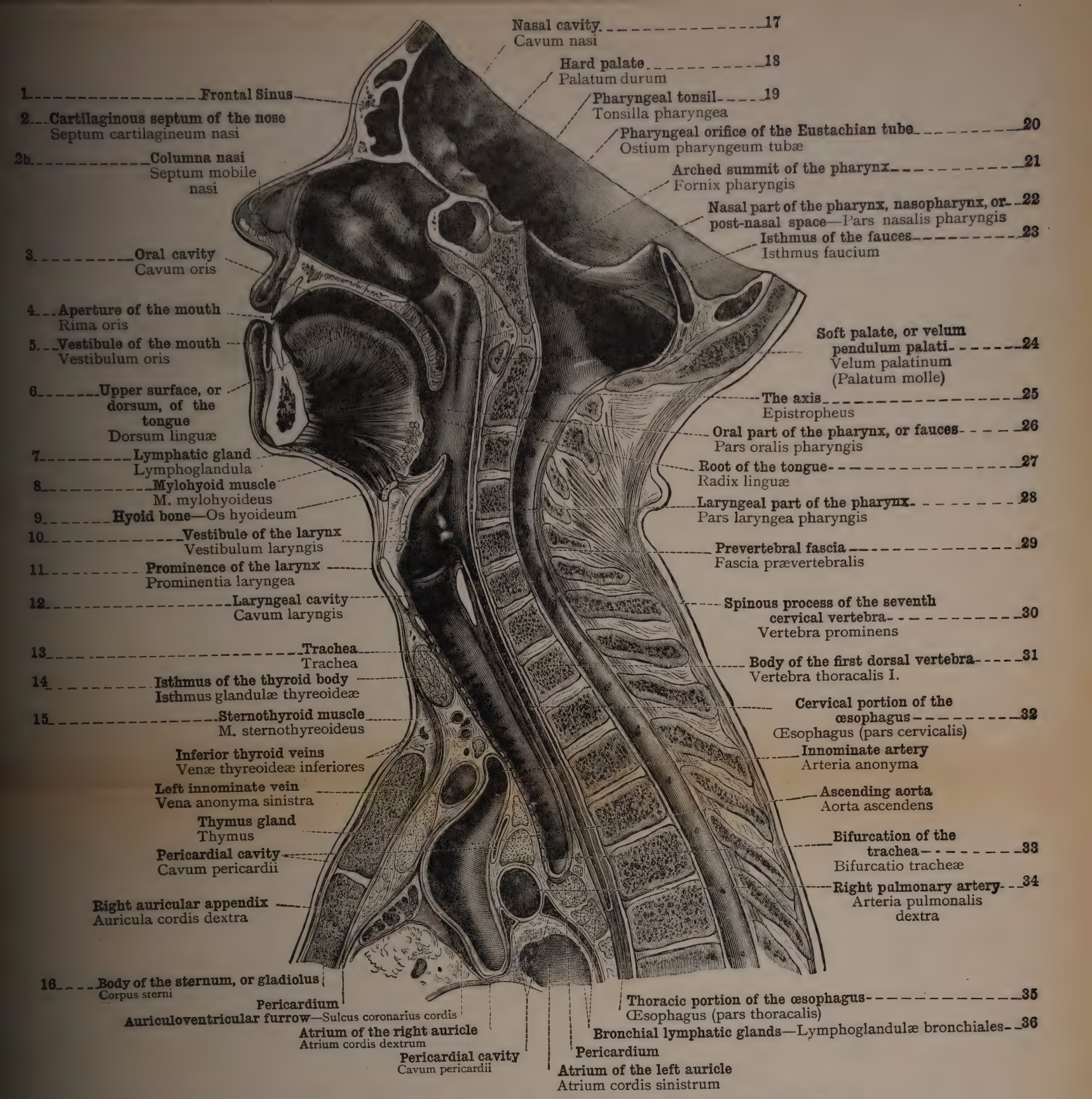


FIG. 190. — MEDIAN SAGITTAL SECTION OF THE ENTIRE VOCAL AND SPEECH TRACT.

fourth effect, viz., the sounding-board function which relatively large bony areas may have in radiating the vibrations transmitted to them by

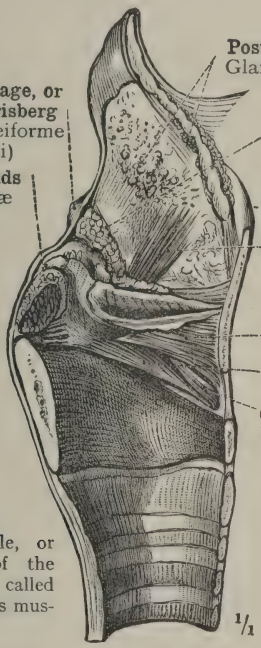

Post-epiglottic glands 0
Glandulæ laryngeæ anteriores
7 Cuneiform cartilage, or cartilage of Wrisberg
Tuberculum cuneiforme (Wrisbergi)
3 Post-arytenoid glands
Glandulæ laryngeæ posteriores
Glands of the aryteno-epiglottic fold 1
Glandulæ laryngeæ mediæ
Cushion, tubercle, or pulvinar of the epiglottis 2
Arymembranaceus muscle (var.) 3
M. arymembranaceus (var.)
Arytenovocalis muscle[3]
M. vocalis or vocal cord 4
Lateral crico-arytenoid muscle 5
M. crico-arytænoideus lateralis
Cricothyroid muscle 6
M. cricothyreoideus
3. Arytenovocalis Muscle, or posterior-anterior fibers of the vocal cord or glottal wedge, called by Ludwig portio aryvocalis musculi thyreo-arytenoidei.
1/1

FIG. 191. — THE MUSCLES AND MUCOUS GLANDS OF THE LARYNX, AS SEEN FROM WITHIN IN THE LEFT HALF OF A SAGITALLY-HEMISECTED LARYNX.

air and surface conduction from the glottal lips. Herein the nasal and buccal cavities would play the most important part. But the effect of the hard back walls of the pharynx cannot be omitted.

CHAPTER XXI

THE ADAM'S APPLE OR LARYNX — HUMAN BROADCASTING STUDIO

"The *larynx*, a cartilaginous box on the top of the trachea, the exterior projection of which is familiarly called the Adam's apple, in allusion to the fabled origin of this part, which was anciently said to have owed its existence to Adam's fatal offence in swallowing the forbidden fruit." Presumably so called by reason of those choking engorged throat sensations we get preliminary to a crying spell or when things are not going just right. "The whole larynx is the immediate seat and general instrument of vocal sound."

WILLIAM RUSSELL (1897).[1]

The Adam's apple (**larynx,** #11 Fig. 189) is so well known that every reader has no doubt felt it as the hard, sharp-pointed part of the neck which lies squarely under the chin, or rather, back jaws. If not, he would do well to locate it by feeling for it with his thumb and forefinger.

Voice. This larynx houses the organ which produces the voice. This fact he can, and should, also prove for himself, by placing his finger on it and pronouncing a prolonged " z-z-z-z-z-z " which will make it possible for him to feel the buzz created by the vocal cords inside. He will note the absence of the voice by pronouncing a prolonged " s̈-s-s-s-s̈-s," or he may compare a prolonged voiced " oo-oo-oo-oo " (*u-u-u-u*) with a whispered one.

Material. This part of the Adam's apple is composed of cartilage. It is universally more pronounced in the male than in the female, and in the mature individual than in the child. These cartilages usually show more of a tendency to ossify, especially in the male, after the age of maturity is reached; and for this reason they are as a rule more visible in X-rays of the latter; and likewise more so in the mature than in the child.

Structure. The *larynx,* as we have before said, really forms but the termination of the *trachea* (Fig. 174), or tube which comes from the lungs. We have likewise said that the *hyoid bone* (#2 Fig. 187) is a part of the

[1] Russell, William; reëdited by Francis T. Russell. *Vocal Culture,* 8th ed., Houghton, Mifflin and Co., Boston and New York, 1897, pp. 255–256.

larynx so far as its function in speech and voice is concerned. It is sheer nonsense to consider it otherwise. For the larynx, and trachea under it, are suspended from the hyoid bone; and the latter is in turn held up by the *middle constrictor* (which forms a band around the middle pharynx) and the powerful muscles attached to the tongue and lower jaw.

So this *hyoid bone* with the membranaceous and muscular walls which connect it to the *thyroid cartilage* (#3 Fig. 186, #7 Fig. 195), and the *epiglottis* (#1 Fig. 186) which slides up and down inside it, forms the separating medium between the *laryngeal tube* and the *pharynx* (# 28 Fig. 190) (or in other words, throat (#26), nose (#17), and mouth (#3 Fig. 190) cavities above it).

Support. Of course all these are supported by the *spinal column* and *skull.* It is to these that the muscles are attached which hold the whole firmly in place, and which permit a varying manipulation of the independent parts thereof.

That part of the Adam's apple (*larynx*) which we feel when we pass the fingers over it is the *thyroid cartilage* (#4 Fig. 187). It is a kind of V-like structure with the apex towards the front, and the open side to the back (Fig. 186). Thus it presents two flat plate-like surfaces, which at the back terminate in an upper (see Fig. 196 and #2 Fig. 186) and lower (#18 Fig. 186) long finger-like horn on either plate. The one which points upward is called the *superior cornu.* The other back horn, which turns down, is the *inferior cornu.* A long muscle (stylopharyngeal #10 Fig. 175 and #24 Fig. 193) extends from the upper cornu to the styloid process on the skull near where the joint of the jaw bone can be felt. This muscle tends to raise the whole larynx and tip the front of the thyroid down. The lower cornu is attached to the *cricoid cartilage* (#17 Fig. 186) and thus forms a hinge which makes it possible for the front of the thyroid to be tipped up and down on the cricoid, while this inferior cornu, on the other hand, is held in a more or less fixed place.

Vocal Cords. The vocal cords (glottal lips #6 Fig. 192) themselves open like a **V** if it is laid down flat (#5 Fig. 197), that is, they lie horizontally within the Adam's apple with the apex of the **V** attached to the front (anterior) middle of the *thyroid* (#7 Fig. 195, #4 Fig. 197, and #11 Fig. 189). The part which opens and closes is at the back, attached to the lower processes of the *arytenoid cartilages* (Fig. 195) which are mounted one on either side of the *cricoid* (#17 Fig. 186).

The back (posterior) part of the *cricoid cartilage* (#17 Fig. 186) is made up of a flat plate and is therefore not open like the *thyroid*. This plate also makes the rear cricoid considerably taller than the front part, which is but a ring of essentially the same width as the others on the *trachea* (Fig. 174).

The *arytenoid cartilages* (#20 Fig. 186) are the most striking part of the structure which controls the function of the vocal cord. If the thumb is stretched out horizontally in front and the index finger is held straight up,

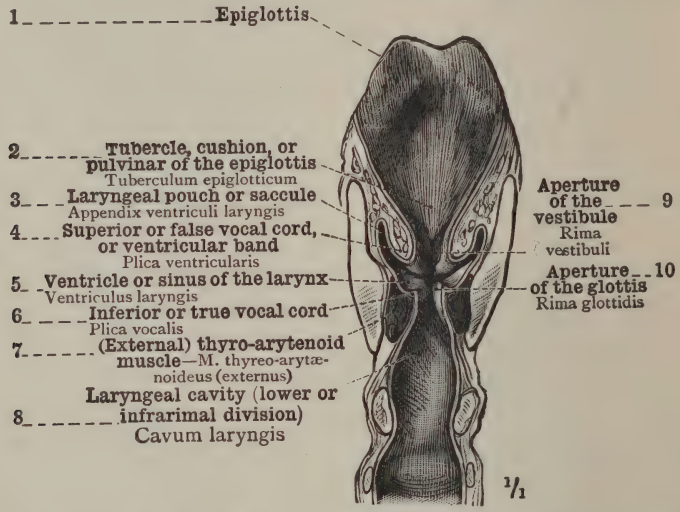

1 Epiglottis
2 Tubercle, cushion, or pulvinar of the epiglottis
Tuberculum epiglotticum
3 Laryngeal pouch or saccule
Appendix ventriculi laryngis
4 Superior or false vocal cord, or ventricular band
Plica ventricularis
5 Ventricle or sinus of the larynx
Ventriculus laryngis
6 Inferior or true vocal cord
Plica vocalis
7 (External) thyro-arytenoid muscle—M. thyreo-arytæ-noideus (externus)
8 Laryngeal cavity (lower or infrarimal division)
Cavum laryngis
Aperture of the vestibule 9
Rima vestibuli
Aperture of the glottis 10
Rima glottidis
1/1

FIG. 192. — ANTERIOR HALF OF A CORONALLY-DIVIDED LARYNX. THE VOCAL APPARATUS, OR GLOTTIS; THE APERTURE OF THE GLOTTIS, RIMA GLOTTIDIS; THE INFERIOR OR TRUE VOCAL CORD, PLICA VOCALIS, WITH THE LABIUM VOCALE, THE SUPERIOR OR FALSE VOCAL CORD, OR VENTRICULAR BAND, PLICA VENTRICULARIS; THE VENTRICLE OR SINUS OF THE LARYNX, VENTRICULUS LARYNGIS, AND THE LARYNGEAL POUCH OR SACCULE, APPENDIX VENTRICULI LARYNGIS.

an idea as to how they are formed may be secured. If the thumbs are pointed forward and the hands, thus shaped, are placed at the sides of the neck it will be possible to see how the arytenoids are set on the back part of the *cricoid* (#10 Fig. 186). The back end of each vocal lip will then be attached to a thumb; and as the two are moved together, it will be seen that the opening of the *V* will thus be closed and the *vocal lips* brought together with but a slit (*glottis*) between. But if the tips of the thumbs are put together the cords may be closed and a triangular opening yet left between the cartilages (#10 Fig. 186). Or if the base of the

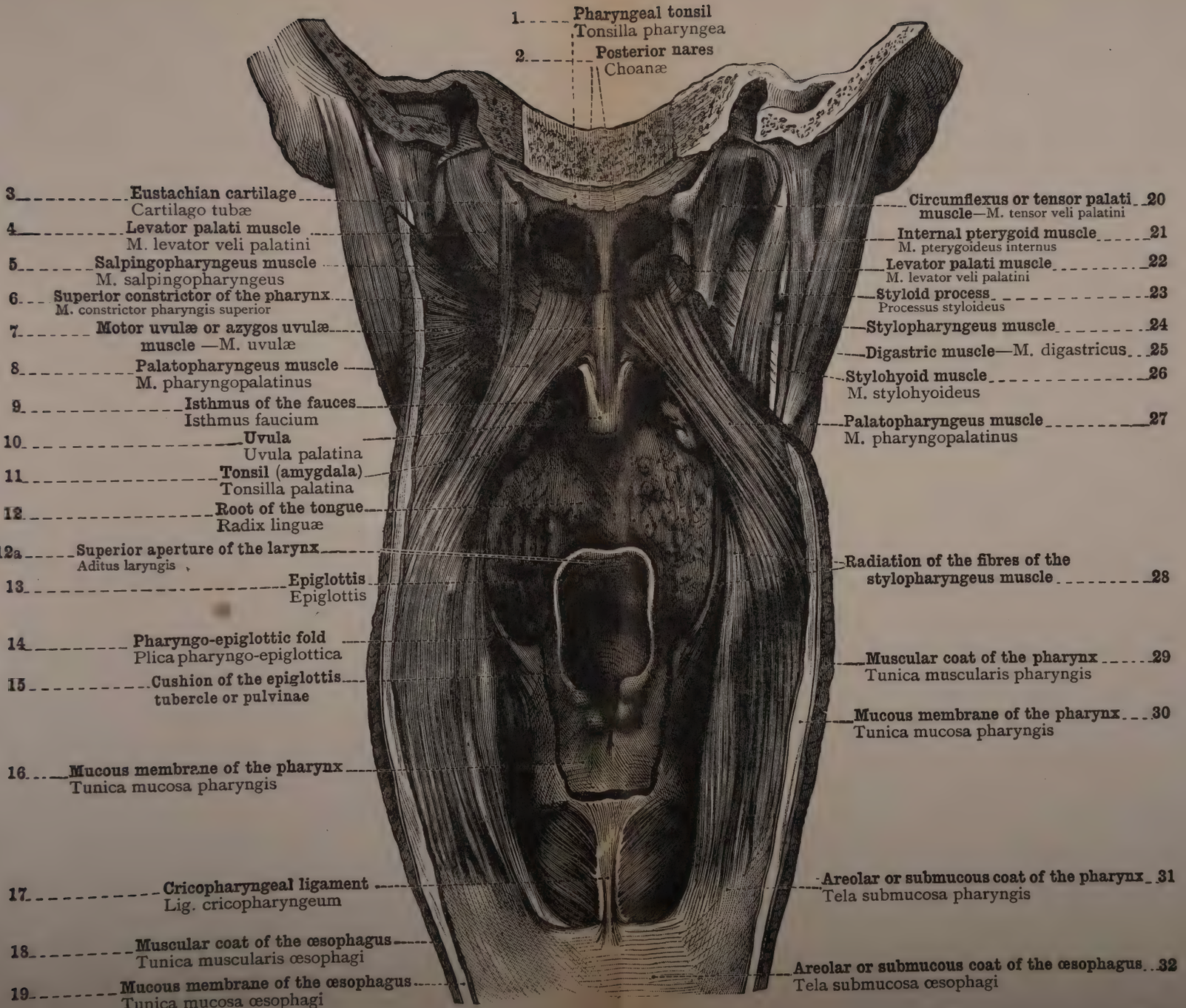


FIG. 193. — MUSCLES OF THE SOFT PALATE (VELUM PENDULUM PALATI), AND THE VERTICAL MUSCLES (ELEVATORS) OF THE PHARYNX DISPLAYED BY OPENING THE PHARYNX FROM BEHIND BY A MEDIAN LONGITUDINAL INCISION AND REMOVING THE MUCOUS MEMBRANE.

thumbs are put together and the tips pointed out, note that the glottis, or vocal cord slit, is stretched open, even though the arytenoids are brought together. These operations will be discussed again when we consider the arytenoid muscles.

A Laryngo-Periskopik Observation. It is also of interest to note that the prongs represented by the index fingers may be tipped forward, and hence those which correspond to the thumb will tip downwards. The laryngo-periskop of the author shows some such movement to be regularly taking place in the production of very low tones, after the subject has passed his middle register; also of certain vowels; and many types of differences in voice quality. The effect on the tone may then be twofold. *First*, the apparent tendency is to relax the cords and thus lower the pitch. *Second*, the forward tipping of the perpendicular prongs represented by the index fingers causes this part of the *arytenoids* (#6 Fig. 186) to move towards the cushion of the *epiglottis* (#1 Fig. 189, #10 Fig. 190) which manifests an even more striking movement towards them and the *cartilages of Wrisberg*. This creates a very small aperture above the vocal cords, through which the sound produced by the latter has to escape. Hence a deadening effect is exercised especially on the upper partials of the complex tone; and the fundamental pitch is lowered because the movement is slowed down — all by reason of the friction created by the air and sound surging through the very narrow opening above them, and not necessarily by reason of any additional relaxation in the cord muscles at all.

What We See. Actually, of course, what we see when we look at the vocal cords through the author's laryngo-periskop, his autofaryngoskop, the ordinary laryngoscope, the autophonoscope, or other such device, is not the projections of the arytenoids. The little perpendicular projections which we see as two small red humps in the back of the throat are mounted on the superior arytenoid processes, and are called the *corniculo laryngis* or *cartilages of Santorini* or just corniculates (#6 Fig. 186 and #7 Fig. 189). The ones slightly to the sides and forward thereof are the cartilages of Wrisberg. (See #7 and #6 Fig. 189.) Not enough attention has been paid to their possible function, and so far as the author knows, many such processes similar to that described in the last paragraph above have not heretofore been noted.

CHAPTER XXII

THE EPIGLOTTIS AND TONAL QUALITY

> "It is quite plain . . . that the lid" (of the epiglottis) "is the means of more or less suddenly and abruptly turning the tone-waves and of directing them under one angle or another against the back of the throat whence they are reflected into the mouth. We are therefore justified in concluding that the lid has some considerable influence upon the quality of the voice. It may thus be the cause of certain characteristics which enable us to recognise the voice of a friend though we do not see him; and it may also account for some similarities of voice which are found in many families, just as there are similarities of features."
>
> BROWNE AND BEHNKE (1887).[1]

Epiglottis. The general tendency has been to think of the epiglottis (#1 Fig. 192 and #13 Fig. 193) as if it were nothing but a trap door serving to close off the "Sunday throat," or interior larynx, while we swallowed food and liquids. In performing this function it was supposed that the tip went down and the larynx came up, until the latter closed on to the back edge of the voice box itself. It was reasoned that the food would then slide down over the top into the esophagus.

The physicist has added to the apparent common sense of this reasoning by pointing out that long sound waves would immediately permeate into every nook and cranny of such a small cavity as that represented by the mouth and throat; and therefore that the possibility of this type of deflection, implied by the authors quoted in the above introduction, would be remote. Certainly it would be true that differences in voice quality could not be accounted for by the angles they refer to.

The Need for More Attention to the Epiglottis. So it is little wonder we have come to devote less and less attention to the possible function which the epiglottis may have in creating differences in speech and voice. But the present author must now perforce revert to something closely akin to the viewpoint espoused by earlier writers. However, in so doing,

[1] Browne, Lenox, and Behnke, Emil. *Voice, Song and Speech*, 6th ed., G. P. Putnam's Sons, New York, 1887, p. 62.

he must make it clear that the position taken by the physicist is fully justified. The sound produced by the vocal cords must of necessity permeate the whole cavity, and that almost instantly. So we cannot assume the existence of straight-angled deflection lines such as those pictured by Browne, Makuen and Muckey [2] — angles created first by the epiglottis which would fling the sound against the back wall of the pharynx, hence making it rebound on the same angle forward against the hard palate, and thence following the law that the angle of deflection must equal that of incidence, outward between the teeth on an angle corresponding to the latter. For this rapid repetition of impulses, creating an indefinitely prolonged and diffused complexity of sound waves cannot be thought of as would be a rebounding ball, or even a concentrated beam of light.

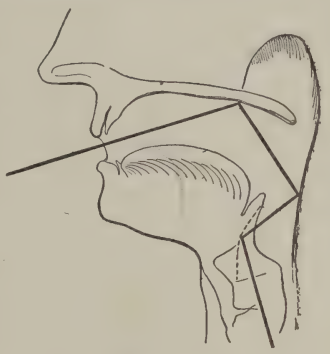


FIG. 194

Usage of the laryngo-periskop and the X-ray photographs, as published herein, should now show us exactly what the epiglottis is doing. Some of our own observations we can hurriedly summarize as follows:

Swallowing. When we swallow, the tongue goes back toward the wall of the pharynx with a downward, pushing movement, carrying the epiglottis with it. However, the tip itself does not need to go down for the whole larynx pushes up forcibly until it closes its upper opening against the base or *cushion of the epiglottis*. Thus the passage into the lungs is effectively closed, and food or water is thereby forced down into the back *esophagus* (#30 Fig. 188 and #19 Fig. 193). This upward movement of the larynx is then of course more extensive in its excursion than any it performs in either speech or singing. The reader can feel how radical it is by placing his finger on his Adam's apple while he swallows. But it must again be reiterated, that the closure is usually really accomplished by the base, or *cushion of the epiglottis*, making a backward movement towards the *cartilages of Wrisberg*. In this approximation, the two effectively close the opening into the voice box. In other words, there may be no such thing, as some have thought, as the *tip of the epiglottis* making an

[2] See Fig. 266 in De Schweinitz and Randall. *Eye, Ear, Nose and Throat*, Saunders, Phila., p. 1175.

independent movement down toward the *arytenoid cartilages* in order to shut off the larynx in swallowing.

The Purpose of the Upper Epiglottis. The purpose of the upper epiglottis may not necessarily therefore be, in any sense, physiological. Rather, it now appears that its primary function is to pinch in on the

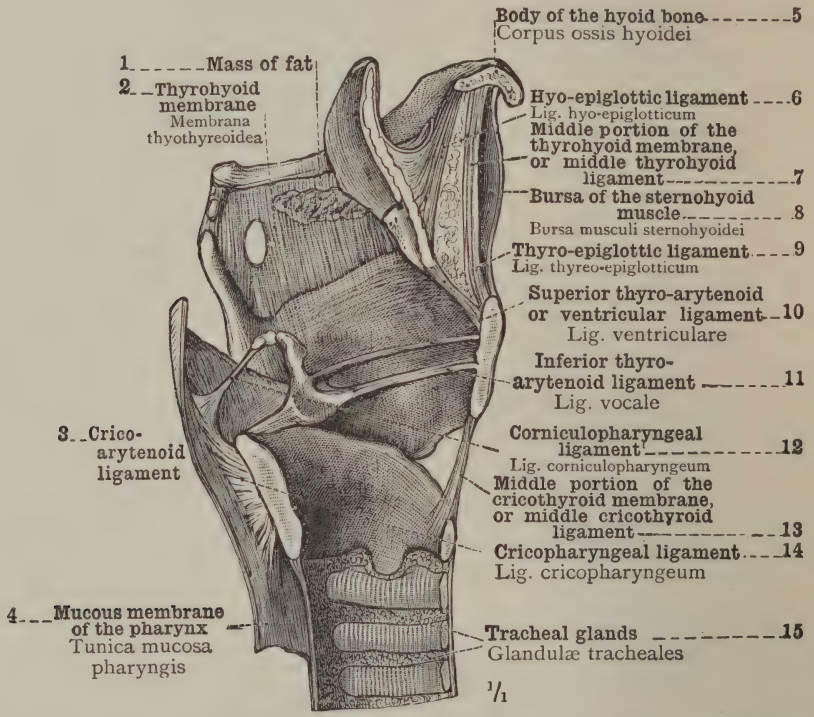


FIG. 195. — LIGAMENTS OF THE LARYNX, AND THE THYROHYOID MEMBRANE, SHOWN IN THE LEFT HALF OF A SAGITTALLY-HEMISECTED LARYNX; SEEN FROM WITHIN.

larynx opening and its issuing tone. If this is accomplished by its base and the whole interior surface of the larynx and the tongue coöperates as it does to produce " ah " (*a*), the creation of a lower cavity resonator with its barrel-like quality is prevented. But it also very evidently serves to deflect the issuing air current with its accompanying sound vibrations, though perhaps not as Browne and Muckey thought. This would at least direct this same air current up into the enmeshing soft surfaces of the *veil of the upper back throat* (also called the *palatine arches*). It would tend

first to mellow, and finally to deaden the sound completely. This we might expect if it did not open too much and the whole back area were constricted. Where these arches are tensed and the velar opening into the nose permits, some have thought the current and tone might be flung with force up against the hard skull sounding-board in the nasal cavities above, so arched as to thereupon deflect the same forward and out and thus provide for a certain type of ringing, yet mellow, vibrant kind of tone which the singer calls " nasally resonant." But the

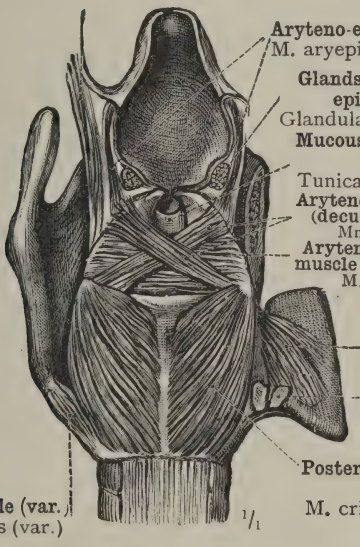


FIG. 196. — THE MUSCLES OF THE LARYNX SEEN FROM BEHIND.

photographs herein show more important facts, viz., where the arches are tensed, spread, and up out of the way, with the velar-opening closed, as they are shown to be in the X-rays of the " ee " (in " peep " *i*) with the tip of the epiglottis sloping well forward, the tone will be flung forcibly against the hard palate and teeth without being enmeshed in the deadening back soft surfaces. In this way the high partials will be accentuated and a quality will be produced which will tend first towards what the singer calls " brilliant," but which, if this accentuation is carried to extremes, will inevitably pass to what is called the " voix blanche " or " white tone," and finally to a metallic, blatant, screeching quality.

Rounding the Outside Lips. Effect. On the other hand, attention must be called to the fact that when the soft lips close in, pucker, or round their corners over this same tone before it is emitted, it is inevitably modified by this latter effect, as the high partials are deadened.

Hard Palate a Sounding Board. Yet a certain amount of sounding-board effect must even then still be present. And a sounding board, which is itself hard, may well add inharmonic components or accentuate certain strident partials (which, where they dominate, impress the ear in much the same way). So the resultant would not be the same as a tone with accentuated partials produced originally by the vocal cords; or one in which part of the partials were deadened through constriction in the soft surfaces lining the throat and palatine arches.

Rounded Vowels. This may well account for the difference heard as between the three vowels in the French " su " (*y*), " si " (*i*), and " sou " (*u*).

Part Played by Epiglottis. The point we wish to make here is that in producing these differences, the position of the epiglottis and its function in deflecting or directing the air current, with its accompanying voice consisting of a concomitant of partials susceptible of alteration by the surfaces and cavities above, must be held to be of vital import. And all those concerned with a study of speech or differences in voice quality would do well, therefore, to observe its varying positions carefully.

CHAPTER XXIII

THE TRACHEA AND CHEST RESONANCE

"In every reinforcing system there is a certain amount of latitude in its function, that is, it will reinforce a particular note and its immediate neighbours a little above and a little below it, the only difference being that in the case of the more perfectly adjusted vibrations the reinforcement is stronger. Open resonators have a wider range of adaptation than the more enclosed. A very little power of expansion, and the reverse, of a resonant hollow, goes a long way towards remedying this inequality, and we find that a range of about one-third can be obtained for a resonator under such circumstances. It is precisely this action that takes place in the voice."

W. A. Aikin, M. D. (1910).[1]

Trachea. As already stated, the larynx (Fig. 174) is really but the termination of the cartilage-ringed tube, or windpipe (which we have called the trachea), leading from the juncture of the right and left bronchi which in turn connect this tube with the lungs.

The trachea is a fibrous and muscular tube about four and a half inches (11.2 cm.) in length, with an inside diameter of around one inch (2 to 3 cm. or in some cases greater). Both the trachea and larynx lie in front of the **esophagus** (#30 Fig. 188), a tube which unlike them is collapsible. Food passes down this tube on its way to the stomach. The larynx itself usually lies on a level with the fourth, fifth, and sixth cervical vertebræ (#28 to 30 Fig. 190). However, it regularly moves up and down as well as back and forward through an excursion roughly as great as the width of a thumb in accomplishing both pitch and vowel changes. The trachea extends from here down to a point approximately opposite the fourth or fifth thoracic vertebra. The rings of the trachea are not actually complete, but are really **C**-shaped, the back part, lying next to the esophagus, being completed by bands of plain muscular tissue. Its interior is covered with a thin layer of mucous membrane which is coated with a film of sticky mucus which serves as a lubricant and catches any particles of dust which may get down this far.

[1] Aikin, W. A. *The Voice*, Longmans Green and Co., London and New York, 1910, p. 115.

Cannot Change Its Own Pitch. As noted, the ring arrangement makes the trachea a flexible tube in its forward-back and side-to-side movement. But it is not susceptible of such elongation or other changes in size as to permit of modifications in its own natural period or cavity tone. The only changes possible are in some of the *bronchioles* (small divisional tube terminations of the *bronchi*, see Fig. 174) which, as they penetrate the lungs, are very soft and so may be more or less distended; and in the varying capacity of the lung cells themselves —

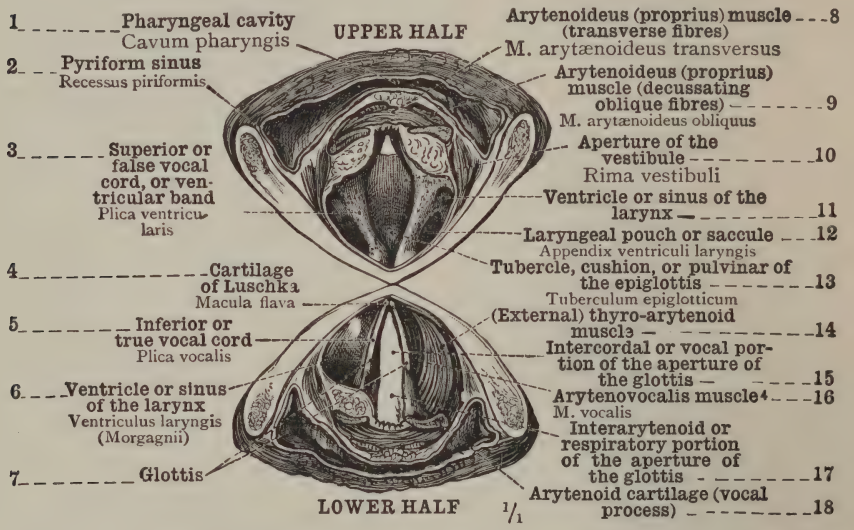

1 Pharyngeal cavity
Cavum pharyngis
2 Pyriform sinus
Recessus piriformis
3 Superior or false vocal cord, or ventricular band
Plica ventricularis
4 Cartilage of Luschka
Macula flava
5 Inferior or true vocal cord
Plica vocalis
6 Ventricle or sinus of the larynx
Ventriculus laryngis (Morgagnii)
7 Glottis
UPPER HALF
LOWER HALF
Arytenoideus (proprius) muscle (transverse fibres) 8
M. arytænoideus transversus
Arytenoideus (proprius) muscle (decussating oblique fibres) 9
M. arytænoideus obliquus
Aperture of the vestibule 10
Rima vestibuli
Ventricle or sinus of the larynx 11
Laryngeal pouch or saccule 12
Appendix ventriculi laryngis
Tubercle, cushion, or pulvinar of the epiglottis 13
Tuberculum epiglotticum
(External) thyro-arytenoid muscle 14
Intercordal or vocal portion of the aperture of the glottis 15
Arytenovocalis muscle 16
M. vocalis
Interarytenoid or respiratory portion of the aperture of the glottis 17
Arytenoid cartilage (vocal process) 18
1/1

FIG. 197. — UPPER AND LOWER HALVES OF A LARYNX DIVIDED INTO TWO PARTS BY A HORIZONTAL SECTION PASSING THROUGH THE VENTRICLES OF THE LARYNX, WITH THE ADJACENT PART OF THE PHARYNX.

whose exits are so limited in size, however, as to make any material change in the pitch of the chest cavity scarcely appreciable.

Nor Modify Partials. Besides the so-called " overtones " or " undertones " traceable thereto cannot (if at all existent) be manifest in any multiplicity. It may rather be said that the whole has but one tone, which is its own characteristic one of more or less constant pitch.

Proof. These observations are proved if we thump the chest with the lungs emptied and compare the tone with the one produced after the air therein is exhausted. We note but little difference in the two pitches heard. Percussion of the trachea during the forced expiration of a deep

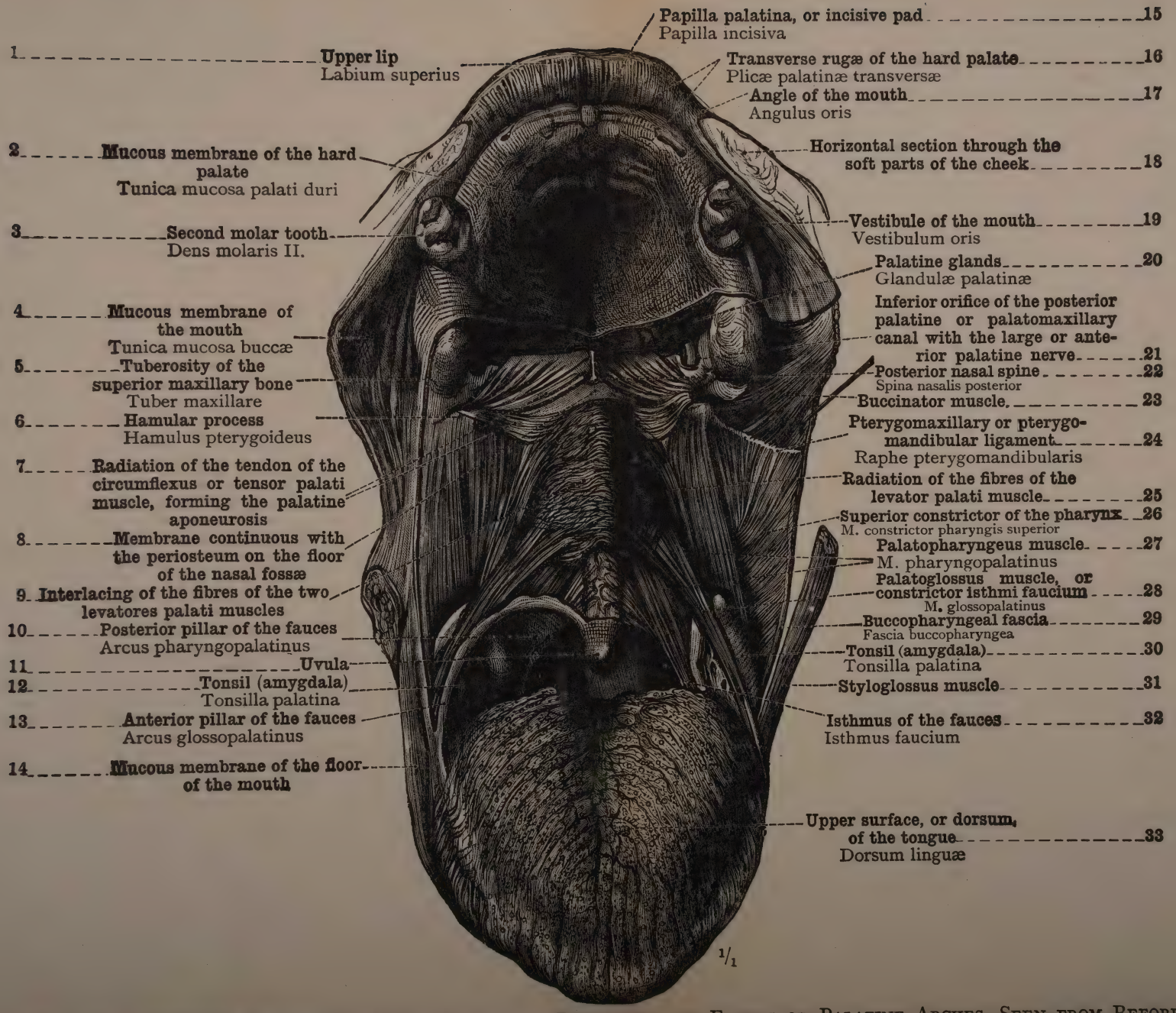

1 Upper lip
Labium superius
2 Mucous membrane of the hard palate
Tunica mucosa palati duri
3 Second molar tooth
Dens molaris II.
4 Mucous membrane of the mouth
Tunica mucosa buccæ
5 Tuberosity of the superior maxillary bone
Tuber maxillare
6 Hamular process
Hamulus pterygoideus
7 Radiation of the tendon of the circumflexus or tensor palati muscle, forming the palatine aponeurosis
8 Membrane continuous with the periosteum on the floor of the nasal fossæ
9 Interlacing of the fibres of the two levatores palati muscles
10 Posterior pillar of the fauces
Arcus pharyngopalatinus
11 Uvula
12 Tonsil (amygdala)
Tonsilla palatina
13 Anterior pillar of the fauces
Arcus glossopalatinus
14 Mucous membrane of the floor of the mouth
15 Papilla palatina, or incisive pad
Papilla incisiva
16 Transverse rugæ of the hard palate
Plicæ palatinæ transversæ
17 Angle of the mouth
Angulus oris
18 Horizontal section through the soft parts of the cheek
19 Vestibule of the mouth
Vestibulum oris
20 Palatine glands
Glandulæ palatinæ
21 Inferior orifice of the posterior palatine or palatomaxillary canal with the large or anterior palatine nerve
22 Posterior nasal spine
Spina nasalis posterior
23 Buccinator muscle
24 Pterygomaxillary or pterygomandibular ligament
Raphe pterygomandibularis
25 Radiation of the fibres of the levator palati muscle
26 Superior constrictor of the pharynx
M. constrictor pharyngis superior
27 Palatopharyngeus muscle
M. pharyngopalatinus
28 Palatoglossus muscle, or constrictor isthmi faucium
M. glossopalatinus
29 Buccopharyngeal fascia
Fascia buccopharyngea
30 Tonsil (amygdala)
Tonsilla palatina
31 Styloglossus muscle
32 Isthmus of the fauces
Isthmus faucium
33 Upper surface, or dorsum, of the tongue
Dorsum linguæ
1/1

FIG. 198. — MUSCLES OF THE SOFT PALATE AND OF THE PILLARS OF THE FAUCES OR PALATINE ARCHES, SEEN FROM BEFORE. APONEUROTIC EXPANSION OF THE TENDON OF THE CIRCUMFLEXUS OR TENSOR PALATI MUSCLE (ATTACHED IN FRONT TO THE TRANSVERSE RIDGE ON THE LOWER SURFACE OF THE PALATI BONE, AND FORMING POSTERIORLY THE PALATINE APONEUROSIS); RETIFORM INTERPLACEMENT OF THE FIBERS OF THE TWO LEVATORIES PALATI MUSCLES.

breath gives further proof of the same observation. The reader may prove this fact for himself.

How to Test Mouth Cavity Tones. If he is not accustomed to hear such differences in cavity tones produced by percussion, he would perhaps do well to listen first to those manifest in variations of mouth size and lip opening. Lay your left index finger against your right cheek where the two rows of jaw teeth spread apart; then while you pucker the lips and raise the tongue in the back throat as if you were going to whisper " oo " (*u*), start flipping the nail of the left finger lying against the cheek with that of your right finger (these should be sharp, quick blows). Now, while still flipping, open the mouth as if you were going to whisper " ah " (*a*). You will note that, because of the larger cavity and smaller lip and velar openings, the " oo " (*u*) flip is much lower-pitched than the " ah " (*a*).

Test on Trachea. If you lay your finger on the trachea just below the Adam's apple (#13 Fig. 190), draw in a deep breath and start flipping it as you exhale, you will perceive that the pitch remains practically constant, with little or no change heard between the tones produced when the lungs are completely full and that observed when they are completely exhausted.

Conclusion. The author cannot therefore but conclude that these assertions concerning the pitch of overtones and alterable chest tones, so commonly made in books on singing and voice modulation, stand without basis in scientific fact. Yet he can well see that the cavity tone, and the damping, " penned-in " function of the trachea, might conceivably operate to " mellow " a tonal quality and likewise give it a " fullness " and " roundness " in much the same manner as do the modern cone loud speakers for the radio, or the long horn for the orthophonic phonograph. Then too the chest might function as a sounding board. The voice mechanism has, however, a big advantage over these mechanical contrivances. For this function may be shunted in and out of play, with an untold number of fine modulations. Perhaps we may recur to this question a little later on.

CHAPTER XXIV

LARYNX MUSCLES — EXTRINSIC

"The extrinsic muscles of the larynx perform all the larger movements of the vocal cords; in addition, through the cricothyroids they help to move and so control the action of the thyroid cartilage on the cricoid."

ELMER KENYON, M. D. (1927).[1]

LARYNX MUSCLES

The muscular system of the *larynx* (or voice box inside the Adam's apple) which we have been considering has been conveniently divided into two parts:

The **intrinsic** system which includes those laryngeal muscles, both ends of which are attached to laryngeal cartilages.

The **extrinsic** system which includes those muscles which are attached to the larynx only at one end, or not at all, but which exert an influence more or less important in the adjustments of the vocal cords.

Extrinsic. (*a*) Those muscles that determine the movements of the larynx cartilages — the **thyroid** and **cricoid:**

1. *Thyrohyoids* (attaching the **thyroid** cartilage to the **hyoid** bone all around, and serving especially to raise the larynx towards the hyoid. See #12 Fig. 182, cf. #3 Fig. 186 and #7 Fig. 195.)

2. The *sternothyroids* (attaching the **thyroid** to the chest bone or **sternum,** thus serving to pull the thyroid down. See #25 Fig. 183.)

3. The *stylopharyngei* (running from the *rear* superior horn of the **thyroid** to a projection on the **skull** close to the joint of the jaw bone, which may serve energetically to raise the whole larynx if the front of the thyroid is kept pulled up, or tip the front of the thyroid downward towards the cricoid if not. See #24 Fig. 193.)

4. The *palatopharyngei* (which like the preceding runs down the throat just back of the tonsil, descending by the posterior pillar from the **rear**

[1] Kenyon, Elmer L. "Extrinsic Laryngeal Musculature," *Arch. Otolaryng*, June, 1927, V, pp. 481–501. An epoch-making study. The author is indebted to Dr. Kenyon more than words will indicate.

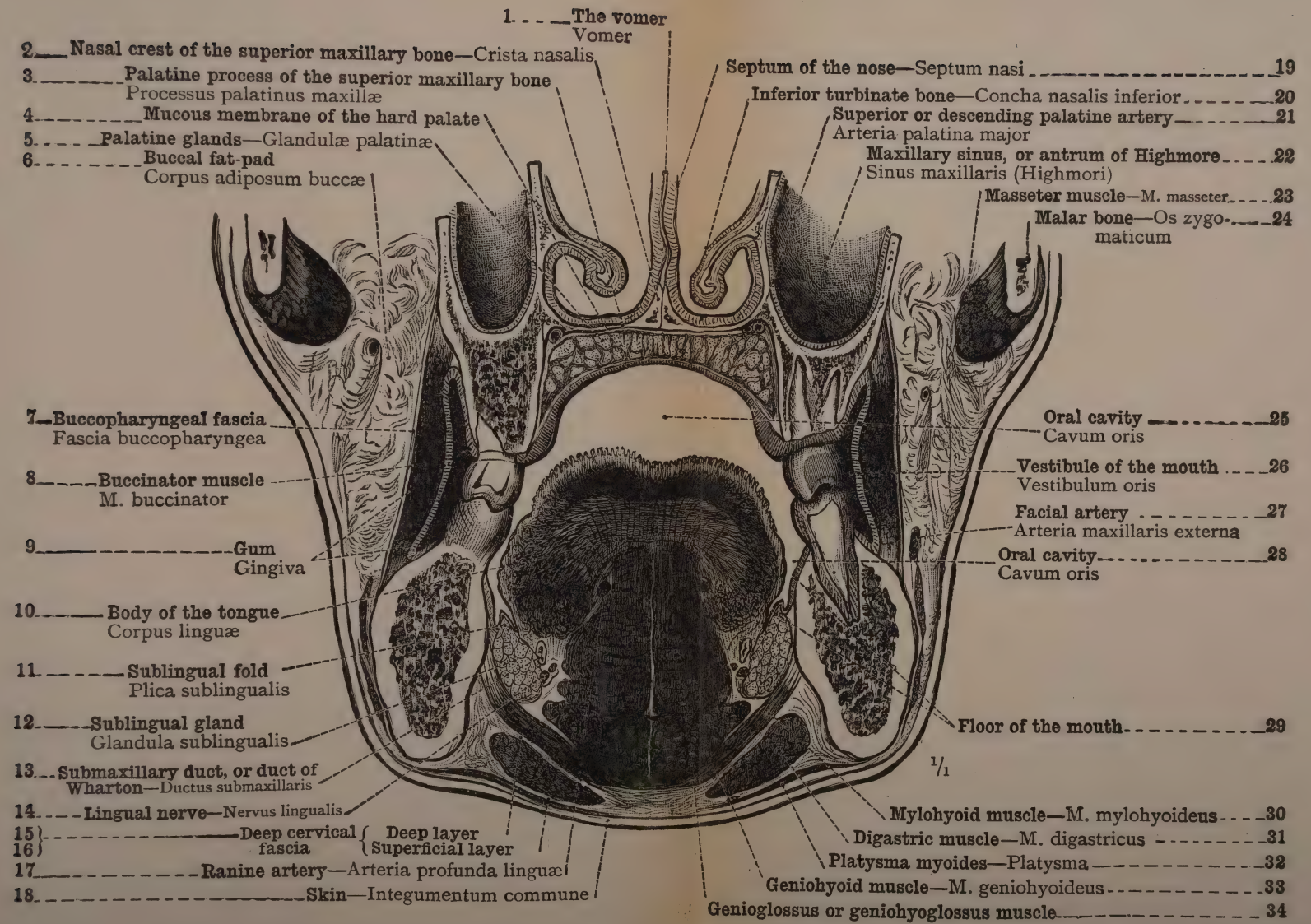
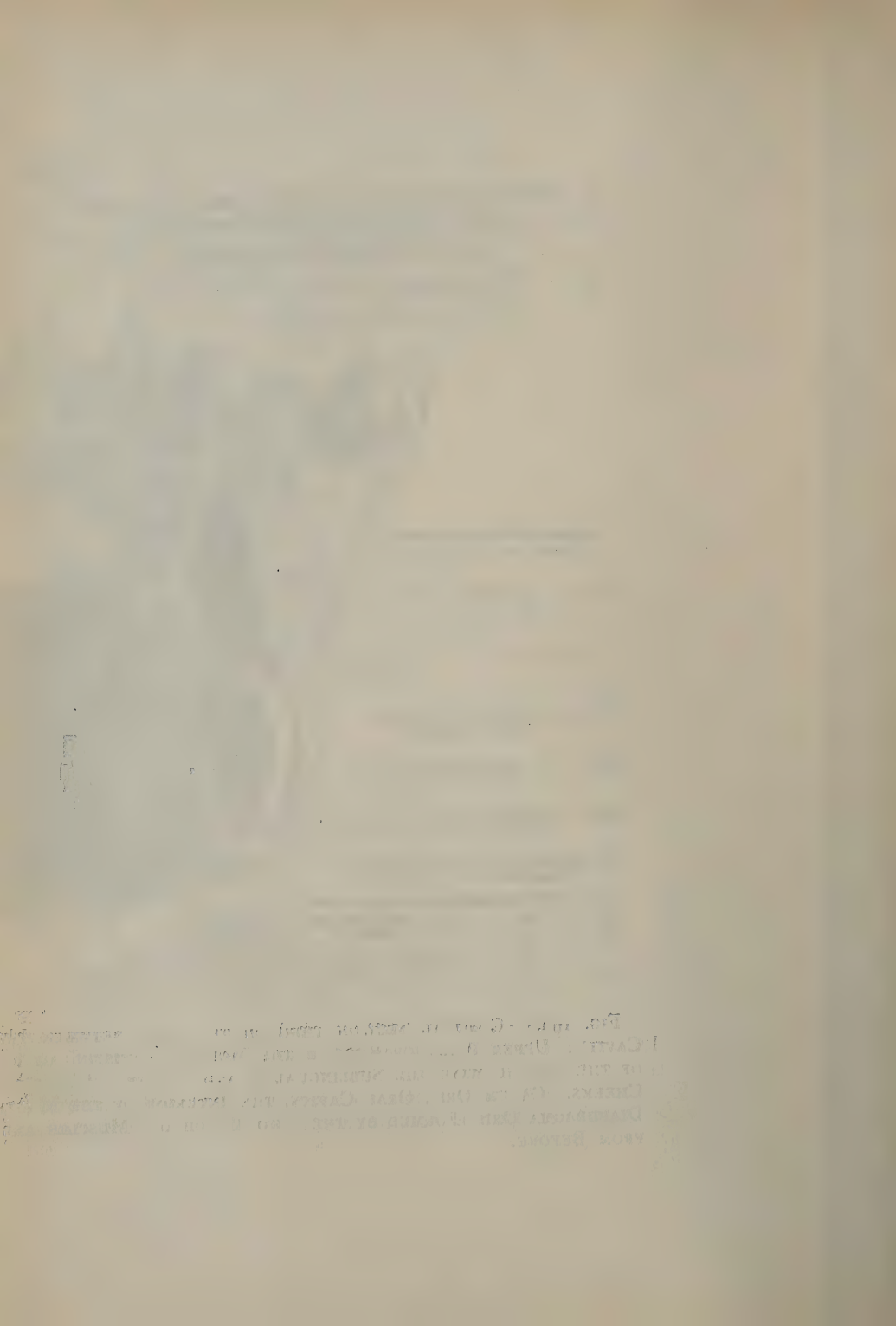


FIG. 199. — CORONAL SECTION THROUGH THE FACE BETWEEN THE FIRST AND SECOND MOLAR TEETH. WALLS OF THE ORAL CAVITY: UPPER WALL, OR ROOF OF THE MOUTH, CONSISTING OF THE HARD PALATE, PALATUM DURUM; LOWER WALL, OR FLOOR OF THE MOUTH, WITH THE SUBLINGUAL GLAND; LATERAL WALLS OF THE MOUTH, FORMED BY THE MUCOUS MEMBRANE OF THE CHEEKS. CAVUM ORIS, ORAL CAVITY, THE INTERIOR OF THE MOUTH; VESTIBULUM ORIS, THE VESTIBULE OF THE MOUTH. THE DIAPHRAGMA ORIS, FORMED BY THE TWO MYLOHYOID MUSCLES AND STRENGTHENED BY THE TWO GENIOHYOID MUSCLES. SEEN FROM BEFORE.



velum partly to the central portion of the pharynx and partly to the **larynx.** This muscle, therefore, serves to raise the larynx and diminish the pharynx. See #27 Fig. 193, #10 and #27 Fig. 198.)

(*b*) The muscles which govern the movements of the **hyoid bone.**

1. *Thyrohyoids* (attaching from around the edges of the **hyoid bone** down to the **thyroid cartilage,** serving thus to control the relationship between the two. See #3 Fig. 186, #2 Fig. 195, #1 Fig. 187.)

2. The *sternohyoids.* See #22 Fig. 183 and *omohyoids.* See #20 Fig. 183. (Functioning to drop the whole larynx and thus elongate the pharynx by reason of the fact that the first connects the **hyoid** to the **sternum** or chest bone, and the second passes through a process of cervical fascia just a little to the side of the center of the **collar bone** and thence over to the **shoulder** as it comes down from the **hyoid.**)

3. *Muscles that control the relation the hyoid bone preserves towards the chin.* Such are the *mylohoids* (see #30 Fig. 199 and Fig. 200) a layer connecting the **hyoid** bone to the **lower jaw** round about; the *geniohyoids* just above the mylohyoid and near the middle (see #33 Fig. 199 and Fig. 200) which likewise connect from **chin** to the **hyoid;** one can feel their tension when he presses his thumbs under the chin and pronounces " ee, ee, ee " (*i*) which can be compared with " ah, ah, ah " (*a*) where the relaxation is noticeable. Some of the lower fibers of the tongue muscle proper (which radiate from the chin in fan shape both towards the tongue tip, sides, and back) called the *geniohyoglossus* (see #34 Fig. 199) likewise connect from the **hyoid** to the **chin.** Then there is the *digastric* (see #31 Fig. 199 and #3, #10, Fig. 182) which runs from the **front** part of the **lower jaw** partly to a **loop on** the side of the **hyoid** and partly through it to the side of the skull. This latter is also therefore one of those which helps keep a certain relationship between the hyoid and the skull. Some of the others of these are the *stylohyoid* (see #3 Fig. 183 and #16 Fig. 175) which connects from the front side of the **hyoid** directly up to the **styloid** process by the ear where the jaw bone has its joint, and which along with the *stylopharyngeus* is one of the most important of the muscles serving to move the whole larynx up and down.

4. *The muscles which control the relationship which the hyoid bone, and hence the whole larynx, has to the tongue.* These are the *genio-hyo-glossus* aforementioned (see #34 Fig. 199) and the *hyoglossi* (see #18 Fig. 183)

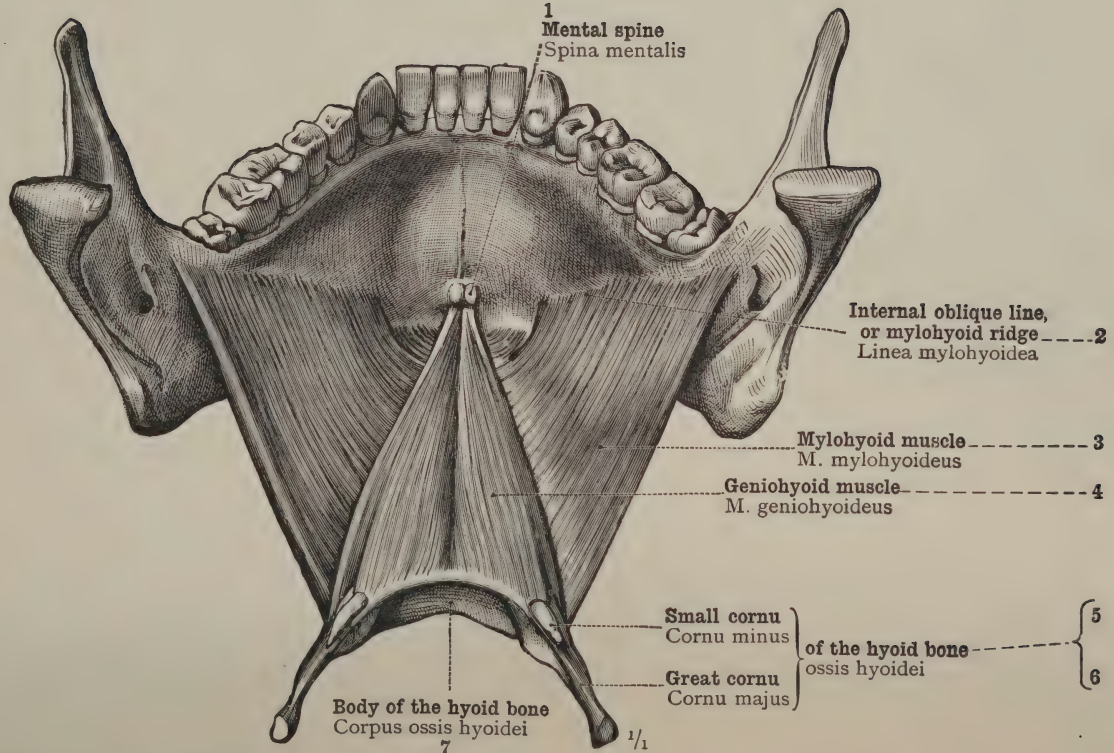


FIG. 200. — M. MYLOHYOIDEUS, THE MYLOHYOID MUSCLE, THE MUSCLES OF THE RIGHT AND LEFT SIDE TOGETHER FORMING A FLOOR BELOW THE ANTERIOR PART OF THE MOUTH, THE DIAPHRAGMA ORIS AND THE GENIOHYOID MUSCLE; SEEN FROM ABOVE AND BEHIND.

which connect all around the **hyoid** and up to the sides, back, and tip of the **tongue,** serving thus, not only to approximate the flat top of the tongue and the hyoid, but to pull the tongue back and down, and where the tongue is held in position by other muscles, to pull the whole larynx up and forward, providing certain of its other muscles are properly relaxed.

5. *Middle constrictor* (see #17 Fig. 175). This is one of the three powerful band muscles which form part of the side walls of the pharynx which runs from along the top edge of the **hyoid** upwards and backwards toward the **spinal column** and thus controls their relationship.

(*c*) Those muscles which by **controlling certain movements of the tongue serve to function in shifting the larynx.**

1. *The styloglossi.* These run from the tip all along the sides of the **tongue** and up to the **styloid** process (see #15 Fig. 197), thus serving to draw the tongue up and back, and hence pull the whole larynx, including the hyoid, in the same direction providing there is no opposing tension.

2. *The palatoglossi.* These muscles (see #13 and #28 Fig. 198), serve to do much the same thing.

(*d*) The muscles which hold the whole **larynx,** including the hyoid bone, firmly in place against the **spinal column** and likewise delimit the movements of the **thyroid cartilage** and **hyoid bone** which we call the *constrictor muscles* (see #5 and #21 Fig. 183).

(*e*) The muscles which raise and lower the jaw bone and thereby influence all those which directly or indirectly attach to the same: *temporal, masseter* (see #14 Fig. 183, #23 Fig. 199, and #28 Fig. 202), and *pterygoid* (see #31 Fig. 202).

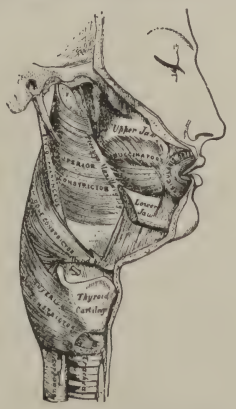


FIG. 201.—EXTRINSIC MUSCLES OF THE LARYNX.

Function. We see that these extrinsic muscles thus serve primarily to attach the larynx to the skull and to the spinal column which supports it. But they not only hold it in place, powerful as many of them are that anchor it firmly in any position desired; they operate to move it upwards, and backwards, or forwards. Its downward movements either of the whole or of parts thereof are brought about, for the most part, by those of these

muscles which attach at one end to the chest bones and shoulder blades; whereas its upward and horizontal displacements are accomplished by those which attach to the skull, chin, and spinal column. We have also observed that some of them may help to, or actually serve to, rotate one part on another; likewise that their play may force material modifications in certain other interior laryngeal positions and function; all of which will thus radically modify differences in pitch and quality in the voice. We call them *extrinsic* first, because they are the exterior laryngeal muscles, and second, because they are easily so classified by reason of the fact that but one end of the muscle attaches to the larynx. It is obvious that their function is of such vital importance as to require careful study on the part of anyone who proposes to give any adequate consideration to the problems involved in speech and differences in voice quality. In fact, Dr. Elmer Kenyon[2] concludes:

> "The extraordinary part of the mechanism of the larynx lies . . . in the manner in which the thyroid cartilage and the thyro-arytenoid muscles transmit the movements of the extrinsic mechanism of the larynx to the vocal cords."

[2] Kenyon, Elmer, M.D. "Relation of Oral Articulative Movements of Speech and of Extrinsic Laryngeal Musculature in General to Function of Vocal Cord," *Arch. Otolaryngology*, June, 1927, V, p. 482.

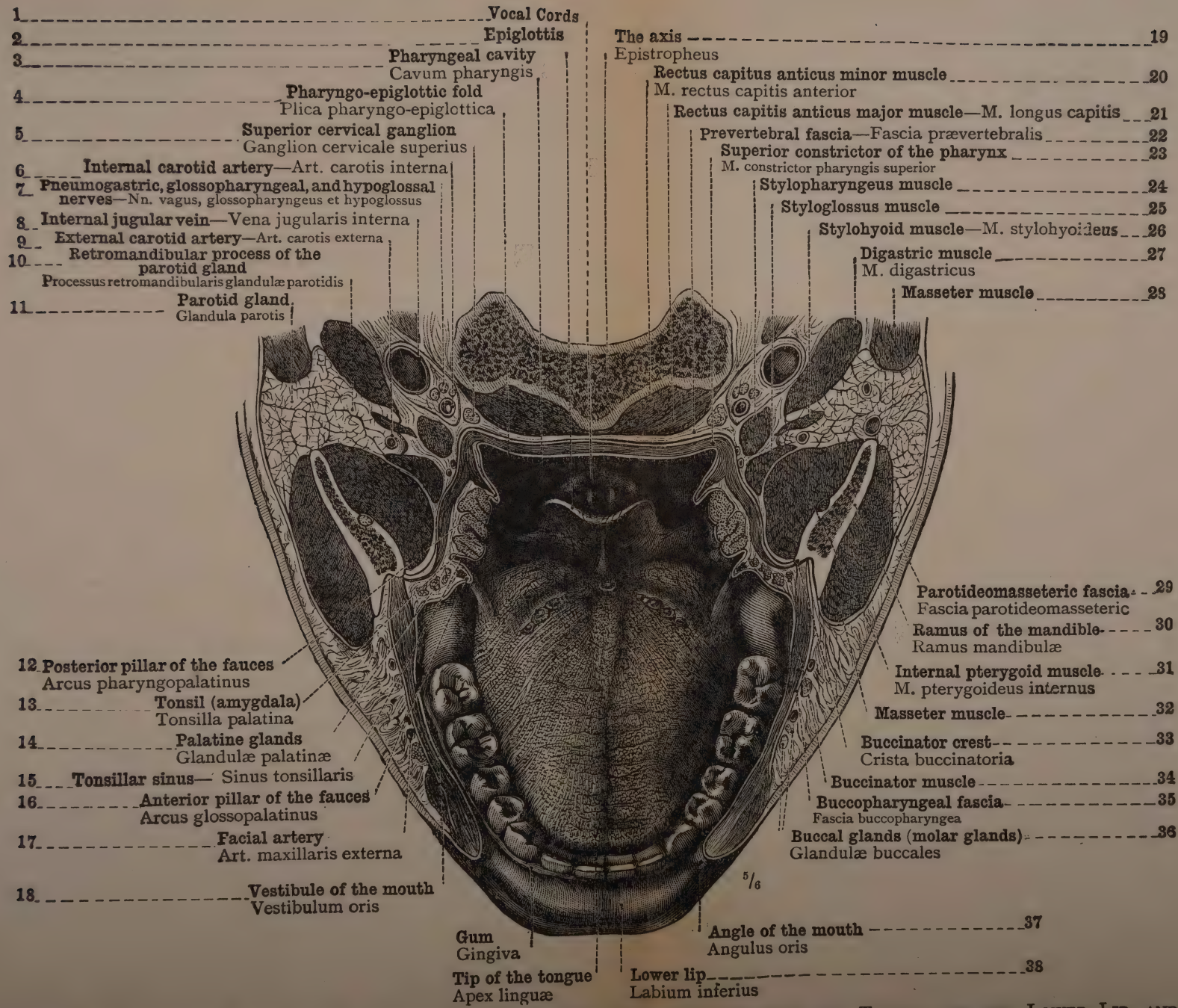


FIG. 202. — LOWER WALL OF THE ORAL CAVITY, OR FLOOR OF THE MOUTH, WITH THE TONGUE AND THE LOWER LIP, AND THE MIDDLE OR ORAL PORTION OF THE PHARYNX (FAUCES), SEEN FROM ABOVE. A HORIZONTAL SECTION WITH CUT MADE ALONG THE LINE OF THE LOWER JAW TEETH.

CHAPTER XXV

INTERIOR VOICE-PRODUCING ORGAN

"In quiet breathing, and after death, the free inner edges of the vocal cords are thick and rounded, and are also tolerably widely separated behind through their attachment to the arytenoid cartilages. . . . During phonation the cords approximate behind so as to narrow the glottis. At the same time they become more tense and their inner edges project more sharply and form a better defined margin to the glottis. . . . These various changes are brought about by the delicate co-ordination of the small muscles which move the cartilages to which the cords are fixed. . . .

"The movements of these important cartilages are controlled by the intrinsic muscles of the larynx attached to them. In considering the action of these muscles, we must not forget that any given position of the vocal bands is the direct result, not of the action of any given muscle, but of the co-ordinated movement of many muscles and of other forces depending on the nature of the articulation of the arytenoids with the cricoid, and of the cricoid with the thyroid, etc."

HOLBROOK CURTIS, M.D. (1914).[1]

The complex structure of the interior larynx, and the exact function or part played by various elements in its mechanism as they operate to change quality in voice and speech, are all still but vaguely understood. Yet we do know that they are of paramount importance in the effect they may have on both the pitch and quality of the tone.

With the development of the author's laryngo-periskop, it has, for the first time, become possible to study the action of this part of the voice organ as it operates in actual normal speech and singing. This could not be done before because the usage of a laryngoscope mirror of the type utilized by doctors — being the common means available — required that the tongue be forced into an abnormal position in order to get a good view of the vocal cords. The examination, too, was limited to but one vowel which of itself was forced to take on an unnatural quality. So most of the observations reported herein are new. Now that such a natural study is possible, other facts will be added as time goes on. And it is inevitable that with cumulative study much of what the author has said will have to be modified. In short, our present knowledge can

[1] Curtis, H. Holbrook, M. D. *Voice Building and Tone Placing*, 3d ed., Appleton, N. Y., 1914, pp. 23, 24.

be considered but rudimentary and cannot be completed in such a study as this. A great deal of careful observation and research will be necessary in order to establish even the most fundamental facts.

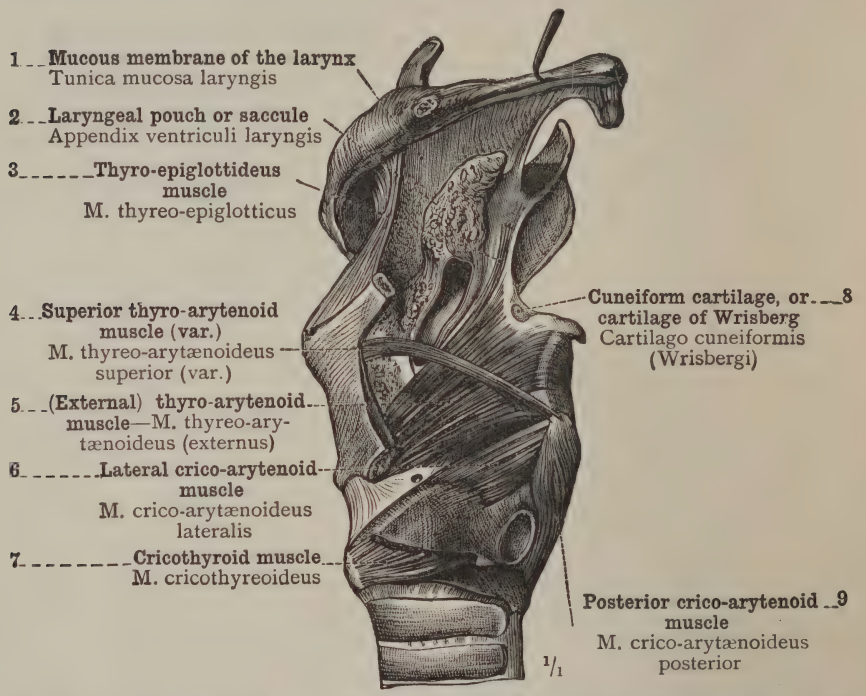


FIG. 203. — THE MUSCLES OF THE LARYNX AS SEEN FROM THE LEFT SIDE AFTER THE REMOVAL OF THE GREATER PART OF THE LEFT ALA OF THE THYROID CARTILAGE.

INTRINSIC MUSCLES OF LARYNX

Let us now look at the interior larynx and examine the various **intrinsic** muscles involved in its control. As before stated, these include only those which have both ends attached to laryngeal cartilages. They may be classified as in the following table:

(a) Those associating parts of the exterior side larynx.

1. *Inner crico-thyroid* (Pulling front end of cricoid and thyroid cartilages together. See #6 Fig. 187. Cf. #7 Fig. 203, #6 Fig. 196, and #6 Fig. 191.)
2. *Outer crico-thyroid* (Pulling back edge of thyroid forward in relation to cricoid or *vice versa*. See #7 Fig. 187, #6 Fig. 196, #7 Fig. 203, #6 Fig. 191.)
3. *Ceratocricoid* (Attaching the back inferior cornu of the thyroid cartilage to the cricoid. See #9 Fig. 196. Cf. #11 Fig. 187, and #13 Fig. 186.)

(b) Back larynx muscles pulling arytenoid cartilages together.

1. *Lower transverse inter-arytenoids* **[see Fig. 204]**. (Since fibers run horizontally: **a.** they pull the arytenoids as a whole together, but toe the vocal cord process out, thus separating vibrating edges. **b.** A pull of the *lateral crico-* and *external thyro-arytenoids* **[Fig. 205]** will offset this tendency, and if greatly tensed, will bring the vocal lips together forcibly by coöperation with simultaneous tension of *interarytenoids*. See #5 Fig. 196. Cf. #9 Fig. 186.)

2. *Oblique arytenoids* (Pull the upper tips or cartilages of Santorini together. Hence approximate vocal lips under conditions indicated in (b) **1,** above. Likewise close the *interarytenoid notch*. See #9 Fig. 189. This may possibly also raise the front processes to which the vocal cords attach. See #4 Fig. 196. Cf. #6 Fig. 186.)

FIG. 204

FIG. 205

FIG. 206

(c) Back larynx, associating cricoid and arytenoid cartilages.

1. *Posterior crico-arytenoid* **[Fig. 207]**. (Where its pull is unhindered by action of other muscles: **a.** serves to raise and toe the front vocal cord process of the arytenoid out. Hence opens the glottis wide as in deep breathing, in a **V**-shaped slit. **b.** Powerful tension in the *external thyro-arytenoid* **[Fig. 205]** or outside fibers of the vocal cord proper pulls at cross purposes, in a way, but along with a *transverse arytenoid* action, may serve to keep the vocal lips together, and tensed, while at the same time raising them, sharpening the edges and clashing them together. **c.** The *lateralcrico-arytenoid* **[Fig. 208]** would apparently merely pull at cross purposes until one or the other tired. Result — nil. Of course the tension need not be great and tiring. The result would then be a state of balance. Such might be the position taken in labored breathing and for the English *h*. As tension in the *lateral* crico-arytenoid begins to predominate the aspiration gets stronger, because the cords approximate more and more. See #8 Fig. 196, #96 Fig. 202. Cf. #10 Fig. 186.)

FIG. 207

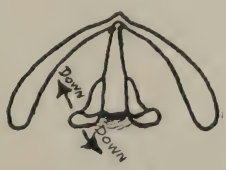


FIG. 208

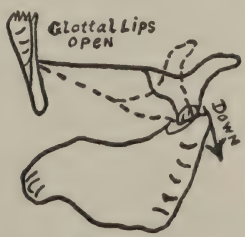


FIG. 209

(d) Interior tensing muscles of the side larynx.

1. *Lateral crico-arytenoid* **[Fig. 209]**. (When unhindered will separate the back edges of the arytenoids, leaving an opening at that point **[Fig. 206]**; **a.** but at the same time will toe-in their front processes to which the vocal cords attach, thus bringing the vocal lips together. The opening left is what we see in a stage whisper and the Castilian " Jota." **b.** If this pull is coupled with a tension in the *inter-arytenoid* **[Fig. 205]** fibers which hold their back edges together, the result will be to close this opening without separating the vocal cords, yet drop and relax them with a consequent lowering of pitch. See #6 Fig. 203, #5 Fig. 191. Cf. #9 Fig. 186.)
2. *Superior thyro-arytenoid* (Much as in (d) **1**, except that it would have little tendency to lower the front prong to which the vocal cord attaches. Yet at the same time it may well serve to materially relax the vocal lips even though kept together in vibrating position. **[Cf. Fig. 211.]** The possible influence of this muscle has heretofore been all too much disregarded, for as will be seen it may play a very important part in altering speech and voice quality. See #4 Fig. 203.)
3. *External thyro-arytenoid* (Often treated as a part of the vocal cord proper. See #1 Fig. 218 and study fiber distribution. See (e) below. However

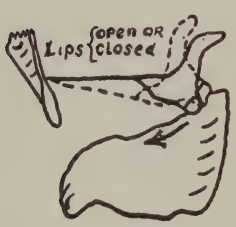


FIG. 210

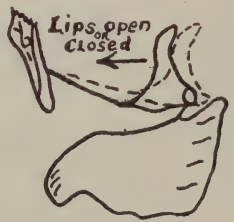


FIG. 211

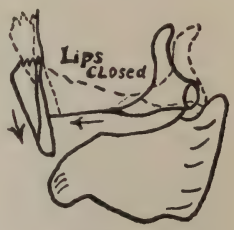


FIG. 212

its fibers attach at so many separate points that each group should be treated individually, since they may all perform different functions. Here we confine ourselves to the lower fibers shown in #5 Fig. 203, which attach to the arytenoid cartilages. They will tend to toe-in the front prong and hence approximate the vocal cords, providing the *inter-arytenoids* **[Fig. 211. Cf. Figs. 204 and 205]** keep the back edges together at the same time. They will likewise tip the arytenoid cartilages down and pull them towards the front or Adam's apple; so by both processes the vocal lips are shortened; yet since this muscle is a part of the vocal cord **[cf. Fig. 213]** if it tenses one would expect the pitch to be raised; this function must therefore also radically affect quality. Yet as will be seen **[cf. Fig. 211]** tension in the lowest fibers will not necessarily produce the same effect as it would in those which attach up towards the cartilages of Santorini. See #5 Fig. 203, #14 Fig. 197, and #7 Fig. 192.)
4. *External " thyro-Wrisberg " fibers* (We have created a name here to cover that part of the muscle (d) **3** above which attaches in the neighborhood of

the cartilages of Wrisberg (#8 Fig. 203 and #6 Fig. 190). Time and again herein, we have pointed out the evidently important part played by a constriction between these cartilages and the cushion of the epiglottis. See text following. Tension in these fibers might spread the cartilages, but perhaps also help to approximate them and bring about the above constriction with the help of the *arymembranaceus* and *ary-epiglottal* muscles referred to in (g) **1** and **2** below. See upper part of #5 Fig. 203.)

FIG. 213

5. *Thyro-epiglottal* (These fibers are evidently a part of the muscle just treated, and serve to spread the epiglottal opening into the larynx laterally. They may also help to pull the sides downward and hence approximate the cushion of the epiglottis and the cartilages of Wrisberg. But the lower part of these fibers, it would seem, might function in the opposite manner and tend to pull the base of the epiglottis down, this is true, yet in a general forward direction towards the front of the larynx, hence spreading the front-back opening into the same. See #3 Fig. 203.)

(e) The Vocal Cord proper (also called Glottal or Vocal Wedge; and the pair, Glottal or Vocal Lips — the slit between them being designated the Glottis, Glottal Chink, Aperture of Glottis, or Rima Glottidis.)

1. *Arytenovocalis* (Fibers forming the sharp edge of the *Vocal lip*, also called the *Plica Vocalis*. Function treated textually below. See #4 Fig. 191, #6 Fig. 192, #16 Fig. 197, also Fig. 215.)

2. *Exterior thyro-arytenoid* (Treated in more detail under (d) **3, 4,** and **5,** above; as also in the text of this and the chapter which follows. See #11 Fig. 195, #5 Fig. 203, #7 Fig. 192, and #14 Fig. 197).

(f) The false vocal cord, with the ventricle of Morgagni lying between it and the true glottal wedge.

1. *Ventricular band* (Function considered in text below. Cf. comment under (d) **4,** above; also that in (c). See fold above #4 Fig. 191, #10 Fig. 195, and #4 Fig. 192.)

(g) Cushion of epiglottis and other constricting surfaces in upper larynx. (See treatment in the text material which follows.)

1. *Arymembranaceus* (See #3 Fig. 191).

2. *Ary-epiglottal* or *aryteno-epiglottideus* (See #1 Fig. 196).

3. *Thyro-epiglottal* or *thyreo-epiglotticus* (See #3 Fig. 203).

(Extrinsic muscles coöperating with above three)

4. *Stylo-pharyngeus* (Part of whose fibers radiate in such a way as to serve possibly in distending the upper larynx laterally, and hence in separating the cartilages of Wrisberg. This, however, represents one of the extrinsic muscles, and like 5 which follows, is merely inserted here in order to clarify function. See #28 Fig. 193.)

5. *Hyo-epiglottal* or *hyo-epiglottideus* (see #6 Fig. 195); the *genio hyoid;* and other muscles which tend to keep the epiglottis upright, and distend the upper pharynx.

CHAPTER XXVI

THE GLOTTAL LIPS — HUMAN BROADCASTING SOUND GENERATOR

"Physiologists are quite at issue when they endeavour to determine what kind of instrument the vocal organ resembles; indeed Galien compares it to a flute, Magendie to a hautboy, Despinez to a trombone, Diday to a hunting-horn, Savart to a bird-catcher's call, Biot to an organ pipe, Malgaigne to the little instrument used by the exhibitors of 'Punch,' and Ferrein to a spinet or harpsichord. The last named compared the lips of the glottis to the strings of a violin; hence was given the name *vocal cords*, which they have since retained. The current of air was the bow, the thyroid cartilages the *points d'appui*, the arytenoids the pegs, and, lastly, the muscles inserted in them the power which tensed or relaxed the cords."

DR. WITTKOWSKI.[1]

The fibers constituting the **vocal cord proper** (see #4 Fig. 191, and #5 Fig. 190) are of greatest immediate concern to us. There is one of these cords, as we have already seen, on each side of the interior larynx. When open they look like a V if its prongs are tipped towards you so as to point in the direction of your backbone. In other words, they look like a V lying flat or horizontally, with its apex pointing towards the tip of your chin and the ends towards the back spinal column. The apex is attached right where you can feel the sharp edge of the Adam's apple, and of course the two cords are always together at that point even when you are breathing easily. In this case the fissure between them, which we call the *glottis*, is open as wide as possible. In other words, the closure is made by pushing the prongs of the V together. Each of these prongs, or in other words each cord, is attached to a forward projection of its arytenoid cartilage. And it is the movement of these arytenoids which either bring the cords together or separate them. (This function we shall consider more in detail below.)

Vocal Cords or Glottal Lips. We have been talking of the vocal cords, but they are not really cords at all. They give this impression when we

[1] Wittkowski. *The Mechanism of Voice, Speech, and Taste*, Baillière, Tindall & Cox, London, 1881, p. 1.

look down on them from above. Then we see them as two apparently flat little grayish white strips of membrane which in some subjects may be tinged with pink along their edges towards the ends. They seem to peek out from under heavy, red surfaces which line the whole tube above them and are in constant wondrous play, trembling and pulling this way and that as if they were alive and had an intelligence all their own. It is a fascinating sight to watch one's own vocal cords as they are operating normally in speech and song. One views them as if they were not a part of his own self, and cannot help but be struck with awe at their complex action; especially when he realizes that this wonderful miracle with its astounding result has all these years been occurring daily within his own body and that without his knowing anything about how it worked.

Size of Cords. When the glottal chink is open, those strips we call the cords seem to be around ten to twenty-three mm. ($\frac{3}{8}$ to $\frac{7}{8}$ in.) long (varying considerably with the individual). However, this is no criterion by which to judge their actual length since the surfaces above may hide a large part of the view. And the same thing may be said of their width. They may appear to peep out laterally along their full length from under the red, muscular surfaces above, by from two to seven mm. ($\frac{1}{16}$ to $\frac{4}{16}$ in.) in width.

Not Cords but Sharp-Edged Wedges of Muscle. But this long cord-like strip appearance is deceiving. Actually, each one of these cords is like a *sharp-edged wedge-shaped ridge* jutting out from the side of the *larynx*, or that part of the tube which we feel as the *Adam's apple* and call the *thyroid cartilage* (see #6 Fig. 192). Each of those wedges we call **vocal cords** is in other words a complex mass of muscle which is shaped something like a right-angled triangle. One of the triangle's flat sides is at the top, being the one we look down on: and the other is attached to the side of the larynx. The sloping side of the triangle corresponds to the lower surface of the cord; hence its outer apex represents the edge of the cord. If we made a perpendicular cut through the cords when their edges were together, the *glottis* or chink between them would look like the sway-backed slanting roof of an old house. In other words, from where the

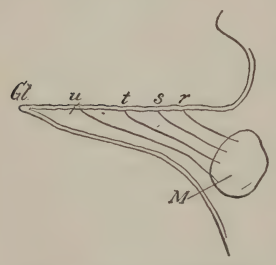


FIG. 214. — MUCKEY'S IDEA OF VOCAL CORD FUNCTION.

two edges come together, the opening gets wider and wider as one passes down towards the lungs, the side presented to the air current by this lower slope of the cords being convex in shape. It is because of this slope that most careful writers prefer to call the vocal cords *glottal lips*, *vocal wedges*, or *vocal shelves*, terms which fit them better. You can see this cupola-like shape as it actually is in the white area in the bottom center of Fig. 216.

FIG. 215. — ENLARGED CROSS SECTION OF A VOCAL CORD. FIBERS OF EXTERNAL THYRO-ARYTEROID ARE SHOWN AT POINT 1.

Some Observations on Function. It will be seen from Fig. 214 that the actual edge of the vocal cord may be made very knife-like — a fact which may have a great effect on the type of tone produced — for under such circumstances we would expect the resultant to manifest an accentuation of high partials, which would give it a more metallic, or even piercing, or blatant, harsh quality. This makes it possible also for the outer thin edge of the cord to be pushed up by the air as an extremely attenuated strip (see Fig. 215); and vibrations of two very thin-edged membranes of this type which are striking together might well produce a harsh, clashing, strident quality in the tone of a type we recognize in cymbals, or in the reed of a harmonica when it gets so loose that it strikes the edge of its opening as it vibrates.

Proof. Metzger [2] has obtained some strikingly good X-ray views of the vibrating vocal cords as they would appear in such a perpendicular section (our Fig. 216; his Fig. 45), published in the excellent study before referred to. They show how the two thin edges might so vibrate as to strike together in the manner just indicated.

[2] Metzger, W. *Psychological Monograph*, No. 17. (1928.)

Metallic and Strident Quality Operation. We have repeatedly noted herein, a fact which bears on this question; viz., when the voice passes to a strident, clashing, high-pitched sound, the false cords and muscular surfaces which lie immediately above the true vibrating *glottal lips* producing the tone, are shown by the laryngo-periskop to be pressing down forcibly, and impinging on the whole outside edge of the *glottal wedge* until nothing but the thinnest strip is left exposed. As a matter of fact these red muscular surfaces above sometimes contract until they blanche and get white, showing an undoubted forcible impingement on the exterior edges of the true vocal lips. Sometimes the *vocal shelves* themselves are no longer visible at all. It is therefore evident that under such circumstances the false cords will not leave any part of the vocal lips free to vibrate except the thin sharp glottal edges. In this case they would naturally be very tense, rather than relaxed as in the above guttural quality. This is the type of tone which was being produced when the vocal cord photographs shown in Figs. 22 and 24 were taken. We shall return to this subject further on when we consider these false vocal cords.

FIG. 216

Pitch Function. Muckey[3] has for years been insisting on some such function being involved, as, for example, in pitch change. This conception of his is represented in Fig. 214. Makuen[4] cites it with the explanation:

> This "schematic representation of the vocal band shows the thyroarytenoid muscle and 'how it sends its fibers into the body of the band.' When this muscle is but slightly contracted the band may vibrate as far back as *r*; but when it is more and more contracted the extent of vibration is limited first to the point *s*, then to *t*, until finally for the highest notes, only the part between *u* and the edge *Gl* is allowed to vibrate." [5]

Soft Pianissimo Processes. On the other hand, the laryngo-periskop shows that when a very soft pianissimo tone is sung, the edges of the vocal cords tend to get round — a process which is facilitated by reason

[3] *Cf.* Muckey. *Natural Method of Voice*, Scribners.
[4] Makuen. "In de Schweinitz," *Eye, Ear, Nose, and Throat*, Saunders, Phila., p. 1173.
[5] See much the same idea advanced earlier by Merkel.

of the fact that the lower surface is of itself normally convex or round. At the same time, the glottal chink is appreciably widened, thus preventing the clashing together of the thin membraneous edges which might produce strident quality. The rounding and spreading also is noted in the falsetto over part of their length. On hollow quality they are even spread to excess.

Certain Vowel Differences. These edges also appear to round off in the production of certain differences in vowel quality if one may judge by what resulted in the experiment manifest under Fig. 16 as compared with Fig. 17. The vowel *i* (" peep ") which was being produced when the latter picture of the *glottal wedges* was taken very evidently manifests a " metallic " quality which, as was stated in the chapter on front vowels, may possibly be accounted for, at least in part, by the thin edges which Fig. 17 seems to show. The quality in the vowel *ɪ* (" pip ") is on the other hand evidently " mellower " than that in *i* (" peep ") and may possibly be partially accounted for in the rounded edges of the *vocal lips* (apparently indicated in Fig. 16). But since these pictures represent only the enunciation of one subject, and the author has no others, it would be unscientific to be too hasty in accepting such a conclusion. These experiments need confirmation.

Further Experiments Now Under Way. Perhaps more and better information may be obtained in the experiments now being conducted by the author on a grant from the Carnegie Corporation and under the auspices of the American Academy of Teachers of Singing with the coöperation of the Eastman Research laboratories and their technical staff. He is in hopes it will be possible to obtain these photographs in rapid moving pictures which will give us at least one hundred exposures per second, and a single exposure at $\frac{1}{1000}$ of a second, thus making it possible to obtain for the first time one single instantaneous view of the *vocal shelves* as they appear at a given instant in normal phonation. The best we have had heretofore is a summation of vibration views, either in all kinds of phases as appears in the figures above cited, and in the X-rays of Metzger; or of a summation of views in the same phase as is shown by the stroboscope — and a hundred instantaneous exposures even of this latter type superimposed one on top of the other may tell us nothing, since the degree of approximation in the cords must undoubtedly vary somewhat each time the stroboscopic slit allows the light to pass. Mean-

time we have to acknowledge that we as yet are not agreed as to just how these *vocal lips* or *lips of the glottis* function to produce voice. Do they serve only to control the emission of puffs in extremely rapid succession as do the lips of the mouth in blowing a trumpet? Or do they actually vibrate as would a membrane with one free edge? Or do they do both? This has been debated for several centuries. The first is the old Dodart theory. The latter but a modification of the later Ferein theory.

Structure. Now let us take a closer look at this main vocal muscle. We may summarize what we said above in regard to their shape, in the words of the anatomist Quain:[6] these *lips of the glottis*

> " are situated at the inner and free edge of a mass of tissue triangular on coronal section. One surface of this mass looks upwards and forms the floor of the ventricle; another looks downwards and inwards, and bounds the lower division of the laryngeal cavity; while the third is external "

and attaches to the wall of the larynx itself. Of course these *vocal wedges* are covered with but the upper termination of the fibro-elastic membrane in which the tracheal cartilages are embedded. As it leaves the trachea proper it sheathes the whole inner surface of the cricoid cartilage. There it separates from the cartilaginous wall, attaching only in front as the apex of the V we talked about above, to the thyroid cartilage, and at the back to a prong of an arytenoid cartilage on either side. The main body of the wedge inside the membrane is formed by the *inferior thyro-arytenoid ligaments*, or the *arytenovocalis muscles* (see #6 Fig. 192) which constitute the **true vocal cords.** In Von Langer and Toldt's[7] anatomy we read:

> " the *elastic membrane of the larynx* exhibits two surfaces, converging from each side of the upper border of the cricoid cartilage upwards towards the median plane, and at the level of the vocal processes terminating in two parallel free borders. This arrangement of the elastic membrane is known as the *conus elasticus* and the somewhat thickened free borders are called **ligamenta vocalia.** At this level the *elastic membrane of the larynx* terminates, being replaced above by a thin layer of areolar tissue."

Fig. 191 will show the muscular fibers which fill in the *conus elasticus.* (See #4, #5, and #6.) There the membrane has been removed and we are looking at the left half of the larynx, the right side of the cut being the front, or in other words the Adam's apple which we can feel under the

[6] Quain. *Anatomy*, 10th ed., III, part IV, p. 155.

[7] Von Langer and Toldt. *Anatomy*, pp. 320, 321. See translation by Paul, M. E., of Toldt, Carl. *Atlas of Human Anatomy*, Macmillan, N. Y., 1928, p. 538.

chin. The best conception of what the *conus elasticus* or triangular *glottal lip* looks like can be had from a study of the perpendicular or coronal section of the larynx, looking from behind towards the front, in Fig. 192. (See #6 and #7 for the *vocal wedge*.) Both the upper and lower halves are shown being divided at the level of the vocal processes in #14 and #16 Fig. 197. Fig. 215, which shows an enlarged section of a vocal cord taken in perpendicular or coronal section, will give an idea as to how the main body of the muscle tapers off into fibers that thin out towards the sharp edge of the wedge.

Dual Nature of Vocal Wedge. This muscle is often treated as consisting of two parts: the **external thyroarytenoid** comprised of the fibers lying nearest the wall of the larynx (*i.e.* the thyroid cartilage), and the *internal thryo-arytenoid* or the **arytenovocalis muscle** including those fibers which thin out towards the sharp edge of the *vocal shelf* or *lip*. As will be seen from #14 Fig. 197, the **external fibers** not only pull the arytenoid cartilage as a whole forward, but have a tendency to toe its front prongs in and thus bring the sharp edges of the vocal wedges much closer together. This facilitates the production of the harsh, " guttural " quality considered further on, or perhaps the clashing " nasal twang," and possibly also the " metallic " or even the " blatant screeching " tonal quality of which we have heretofore spoken, providing the cord were very tense. (See also below.)

The **internal fibers** shown in #16 of the same Figure 197 attach to the front prong of the arytenoid cartilage itself. So if they become *tense* in connection with the tension of the above toeing-in (*i.e.* tension of the external fibers), one would seem to be justified in expecting the " *metallic* " or " *strident* " quality heretofore referred to; but if the internal fibers are relaxed (being in either case forced to clash together by reason of this toeing-in), it would seem to be reasonable to expect a " guttural," or " nasal twang," or some other such " harsh, quack-like " quality to result. All of these qualities may well be abetted, and undoubtedly are, by movements provided in other muscles and surfaces around the cords we have just been considering. Among these, some of the most important are undoubtedly the false vocal cords and other constricting surfaces lying immediately above. In the next chapter we shall call attention to some of our recent observations in regard to these.

CHAPTER XXVII

THE FALSE VOCAL CORDS AND TONAL QUALITY — A SURFACE, NOT RESONATOR MODULATION

"I am much obliged to you for . . . directing my attention to a mistake that has been made in the interpretation by some writers of my views regarding the action of the ventricles of Morgagni, and the ventricular bands, or "false cords." The account of these views that you give . . . in your work . . . is perfectly accurate.

"In my 'Observations on the Physiology of the Larynx' I showed that the ventricles with their ligaments form an important valve, but I said nothing of their relations to voice, with which I believe they have little or no concern."

DR. JOHN WYLLIE (1883).[1]

The **false vocal cord** which shows in #10 of Fig. 195 as the superior *thyro-arytenoid*, or *ventricular ligament* as well as in #4 of Fig. 192, #3 of Fig. 197, and just above #4 of Fig. 191, likewise attaches, as does the true cord, from the thyroid cartilage to the arytenoid. But as will be seen, it is fastened to the latter well up towards the top of its upper or perpendicular prong. It is sometimes called the *ventricular band*. Now that the author by means of his laryngo-periskop is able to see its play in normal speech, singing, etc., it is a surprising thing that it should have heretofore been gingerly recognized and ascribed such a minor place in vocal function. With the exception of Muckey nobody he knows of has referred to it except as the possible creator of a small resonator immediately above the vocal cords. Almost everybody has been rather doubtful as to whether it had any muscular function or not, and some even said that it was not subject to muscular constriction. Among the latter was Dr. Hewson[2] in his reply to Bell.

A. G. Bell — " The first question is: 'Is it possible to constrict the false vocal cords. . . .' "

Dr. Hewson — " I cannot conceive of any muscular fibres constricting the ventricular bands, or false vocal cords."

[1] Wyllie, Dr. John. In a letter to Dr. Lennox Browne, published on p. 236 of *Voice, Song, and Speech*, 6th ed., Putnam's Sons, New York, 1887.

[2] In Bell, Alexander Graham. *Mechanism of Speech*, 8th ed., Funk and Wagnalls Co., New York, 1916, p. 11.

False Cords Do Constrict. Cough. Yet their violent contraction and sudden explosive separation is strikingly manifest now, when one views through the laryngo-periskop what happens when a person coughs. It was said formerly that when a cough became necessary to expel or keep anything out of the trachea or to keep it off of the vocal cords, that the epiglottis came down to " shut off the Sunday throat " and the glottal lips were brought tightly together, then both were suddenly forced up with a violent explosion.[3] As a matter of fact, the primary function of the epiglottis seems to be one involved in speech modification; and in no subject the author has studied has the epiglottis played any such part as that above indicated. The mere thought of or preparation for a cough brings these ventricular bands together in a tight constriction — so tight that not the slightest strip of the true white vocal lips underneath is visible.

Gagging. The same thing may be said of gagging. The false cords come closely together and shut off the entrance into the interior larynx, well up as far as the cartilages of Wrisberg. (See #6 Fig. 189.) Of course in this case, as all have observed, the whole pharynx also constricts. The tongue closes up the back throat and hence also pushes the epiglottis back, much as in swallowing; the velum constricts and closes the nasal passages; and the palatine arches likewise tend to close in on the bow of the rising tongue to shut off even that entrance into the pharynx. All of these movements are often accompanied by a reverse movement of the swallowing process, which results in a tendency to regurgitate and expel the foreign body causing the gagging. In other words, this is the most violent closing movement of which human physiology is capable. In this case nature takes no chances on anything getting into the lungs.

Guttural Quality. Now let us go back to the cough as a starting point. We noted that in preparation therefor, the *ventricular bands* or *false cords* (see #4 Fig. 192) close up sharply. When they are just resting together lightly, as if getting ready to cough, and phonation is started, they and the mucus which gathers between them are set into vibration. Of course all harsh quality of this guttural type, especially on low-pitched tones, is not due to this cause.

Other Mucus Harshness in Tonal Quality. Perhaps we might even say that a harsh quality is *most often traceable to* the vibration set up in

[3] See Dr. Aiken's *statement, op. cit.*

globules of mucus gathered *on* the *vocal edges* proper. Such a concentration of mucus is especially noticeable through the laryngo-periskop in throats manifesting any type of irritation of the vocal cords, and is undoubtedly largely due to nature's well-known process of counteracting inflammation by this means. We sometimes call this type of voice a "hoarse voice." In singers, particularly in the incipient stage, it is manifest at times in nothing more than a roughness of quality. We hear analogous results in piano strings which we load with a drop of sealing wax, etc. So we might expect such non-harmonious quality to result from a little globule, or uneven load of mucus resting on the edge of the vocal lip, especially towards the center where the laryngo-periskop shows that the mucus tends to creep. But since these little drops regularly break under the force of the air current driving through, much as do the crests of ocean waves driven by the wind, the vocal sound may often become even more dissonant by reason of this uneven variation. Of course the natural pitch of the voice is also lowered by reason of such a load gathering on them; for one need not remind the reader that additional weight added always slows up the vibratory rate of any medium.

Smoking. We regularly note now both the lowered pitch (or more "mannish" voices) and harsher unmusical quality in the voices of women who have become smokers. This statement is not just a surmise on the part of the author. In the course of certain experiments on intonation and pitch perception, he studied and recorded the upper, lower, and normal speaking pitch of 360 cultured women from various parts of the United States in 1916. Again last year he had occasion to extend this study and examined another 650 women, a large part of whom were mature college girls, including a substantial percentage who were regular smokers of cigarettes. As is well known, the number of women who smoked in 1916 was extremely limited and most of those studied then were from Mormon districts where, because of their religion, even the men refrain from smoking. The general average voice pitch for this second group (1928) shows a drop of from four full tones to an octave;[4] and in the lower limit, which in 1916 seldom descended to the a (215 d.v./sec.) below middle c^1 (256 d.v./sec.), a striking change was noted, since it was not unusual to find cultured women who were able to descend

[4] See report in summary of results shown by these experiments, recorded under intonation range of men and women on Russell Hearing Test chart, Volta Bureau, Washington, 1920.

with ease to the middle c of the male voice (128 d.v./sec.). I say with ease, but it should be noted that in all such cases, the harsh, rasping quality of the voice was most noticeable. Women with this type of voice claimed to be unable to detect any unusual harshness, however, and though readily acknowledging that they smoked, yet invariably resented any implication that the two might have any connection. However, the facts are patent; and it would appear to be only scientific to warn the singer who desires to preserve the best quality in the voice, that any such irritation should be avoided.

Source of the Mucus. There are a number of glands which lubricate the larynx. The most striking are the *post epiglottic* or *anterior*. (See #0 Fig. 191.) Then there are the *glands of the aryteno-epiglottic fold* or the *middle glands*, most numerous above, where they form a prominence beneath the mucous membrane of the fold referred to " immediately behind the cartilage of Wrisberg, and a chain running thence downwards and forwards along the false vocal cord," . . . (See #1 Fig. 191.) It is these latter which supply most of the mucus which we have been considering. There are, however, the *post-arytenoid* or *posterior laryngeal glands* which form a mass behind the arytenoid cartilage and beneath the cartilage of Santorini. But possible lubrication supplied by these to the vocal cords is not within our concern.

Nasal Twang. When this rather disagreeable quack-like quality in the voice is heard which we designate as a " nasal twang " the laryngo-periskop shows a most striking constriction to be manifest in the interior larynx. This is the quality which is commonly thought of as being characteristic in the speech of certain parts of New England. Recently the radio has been carrying a feature under the name of " Tompkin's Corner " in which some of the speakers ostensibly from Maine give a typical reproduction of the voice quality in question.

The Whole Interior of the Larynx Constricts. The shadow on both sides between the *vocal lip* or *arytenovocalis muscle* and the *false cord* or *ventricular band*, which under normal phonation clearly indicates the *ventricle of Morgagni* or *ventriculus laryngis* (see #3 and #5 Fig. 192) disappears. This fact alone shows unmistakably that the false cords are impinging along the exterior edges of the vocal lips. And when the tonal quality becomes very strident, as it does in public speaking and under emotional strain, they are seen actually to blanche and get white. This

fact indicates that they press so tightly as to force the blood out; and without doubt is additional proof that in so doing they are actually impinging on the true cords or vocal lips, just as they do in the production of a harsh, quack-like, strident, singing tone. Where the tonal quality is distinctly nasal the *cushion of the epiglottis* (see #2 Fig. 192) is often seen almost to close upon the *cartilages of Wrisberg*. (See #6 Fig. 189.) This may be due not only to the pull exercised by the *aryteno-epiglottideus* muscle (#1 Fig. 196) but also to a contraction of the *arymembranaceus muscle* (#3 Fig. 191), and to a downward tipping of the arytenoid cartilages which would throw their superior prongs forward. (Figs. 195 and 191.) When this closure takes place, it will be seen that a sort of cul-de-sac might well be created between the vocal lips themselves and this superior narrowing of the opening. However, it must be said that this is not clearly visible from the top.

Produces " Nasal Twang." Yet if a cul-de-sac is formed there might well result a nasality of quality analogous to that produced by Sir Richard Paget when he lays the open hand against the throat just above the *Adam's apple* and forcibly presses in. And that nasality, on a smaller scale, it is true, might well be expected if we compare it with the well-known result produced by vowels passing into the nose when we have a cold, or when we pinch the nostrils with the fingers and so create a cul-de-sac.

Different Types of Nasal Quality. Prof. T. Earl Pardoe, a brilliant former colleague of the author, was wont to illustrate these varying results and the theory above enunciated as to the effect of nasality as compared with nasal resonance, in these two types of voice quality by vowels, both of which were permitted free access to the nose. One of them was disagreeable; but the other had a tonal quality anybody would be proud to be able to produce. It will be seen, therefore, that we here distinguish between **nasality, nasal resonance,** and **nasal twang.** The latter is primarily traceable to a detestable function of the interior larynx. The first two are traceable, principally, to a function of the nasal passages.

Pinched or Shrieking Tones. Now this often extremely " harsh and quack-like " *nasal twang*, with its inharmonious components, is only a step removed from the louder *piercing*, *blatant* quality in the voice, and from the so-called *pinched* or *constricted* voice. These are not due to the " tongue getting into the back part of the throat," or to " swallowing the

tongue," as some have said. The tongue regularly gets into the back part of the throat in the production of numerous vowels. Such a one is the **ah** (*a*). For the articulation of this vowel a narrowed epiglottal opening, and the elimination of a laryngeal resonator — in other words a placing of the tongue root in the back part of the throat — would seem to be a necessity. Much the same thing may be said of the **ăh** (*æ* as in *pat*); also of the **aw** (ɔ); and likewise of the **oh** (*o*) — though in this case the laryngeal resonator begins to form. If the epiglottal opening is not narrowed as for the production of an **ah** (*a*), the singer may deceive himself into thinking he is producing that vowel when by distending the throat he has actually changed it into an **uh** (ə).

What Happens to Produce These Pinched Tones? Since the quality in question cannot be traced to the supposed throat constriction, we must seek it elsewhere. And the laryngo-periskop throws considerable light on the question. Such tones have been photographed in Figs. 22 and 24. The reader will note the vocal cords are no longer visible, as in Fig. 17, and that the whole interior larynx is set into such violent vibration that the photograph shows " fuzzy " outlines throughout. Of course there are other accompanying manifestations. The *mylohyoid* (#8 Fig. 190 and #3 Fig. 200), and *geniohyoid* (#4 Fig. 200) in coöperation with the *hyo-epiglottic ligament* (#6 Fig. 195) continue to exercise their strong forward pull on the epiglottis for the vowel *i* (" peep "), forcing it to keep its upright position and holding it as far towards the chin as possible. Undoubtedly the *external thyro-arytenoid* (#5 Fig. 203) muscles (whose *internal* fibers constitute the *true vocal cord* (see Fig. 215) are likewise put under violent tension; and as will be seen in #4 of Fig. 203 some of these fibers pass well up to the edges of the *epiglottis* (see #3 Fig. 203), as well as back to the *arytenoid cartilage* (cf. #5 and #6 Fig. 203). On the other hand, that muscle which in good tone production should ordinarily be relaxed, viz., the *aryteno-epiglottideus* or *aryepiglottal* (see #1 of Fig. 196), but which under tension pulls the whole epiglottis back towards the pharynx when the *mylohyoid* (#3) and *geniohyoid* (#4 Fig. 200) do not prevent, is here shown to be violently contracted. Hence all the outside edges of the epiglottis, including the cartilages of Wrisberg, are pulled together, and a lateral contraction of the larynx is manifest which is astounding.

Tonal Quality Resulting. The tone is forced to escape through a regular little chimney of violently contracted surfaces. This fact, in and

of itself, would make the tone more " metallic " in quality. But in addition, the mounting of one of these rigid areas on top of the other, and the forcing of the whole to impinge on the vocal cords, makes it so very difficult for even the little narrow strip of the glottal lips still exposed to vibrate that all the force within their power, as well as that of the lung-bellows, must be brought to bear in order to produce any tone whatever. Of necessity, therefore, they are pressed tightly together, and hence they must clash violently together, just as cymbals are made to do. So it is little wonder that the tone produced is *strident* and *piercing* — that it has a *clashing brass-like quality* which is totally unmusical in its effect on the ear.

Why ? The Reason Is Evident. This tone must inevitably, if the effect of the vibrating mucus which gathers on them is taken into consideration, show a strong accentuation of uneven partials, and even an intermixture of noise or inharmonic elements. It is a well-known fact that nature comes quickly to the rescue with this lubrication when similar conditions develop anywhere in the body. But we need not reason from this alone. The mucus can be seen through the laryngo-periskop. After a very few moments of strain it gathers first in irregular masses all along the edges of the vocal lips. Soon it is seen to pull up into little globules, and these repeatedly break at rapid intervals, thereby inevitably injecting noise, or inharmonic components, into the complex quality of the tone being produced. When these globules break, they of course spray a large area of cord surface again, and so weight down on the vocal cords unevenly. This is one reason why a dissonant effect is produced. And the mere vibration of these globules which are broken by the air column must of course be even more violent in its inharmonic effect. We note this fact when, after a few moments, the voice gets " *hoarse* " and " *husky*," much as it does when disturbed by a cold or any other inflammatory condition. We also realize that mucus has gathered when we hear a lowered pitch, as this is sure to result from the added weight of the mucus load. After a few minutes of such strain it may take hours for even the best voice to become normal again.

Voice " Break." Naturally such violent tension of one muscle pulling with all its force against another cannot hold out indefinitely. We have all tried this when by holding the arm out, slightly flexed at the elbow, and playing one muscle against the other, the attempt is made to pull

the fist toward the face and at the same time keep it out. How long can that position be held? The time is easily counted in seconds. And then what happens? Nature balks. And with all the will power at one's disposal it becomes impossible to hold the position, for the muscles relax in spite of our attempt to keep them taut.

Voice Catch. Sob. Much the same thing happens in the " voice break." Where the singer persists in this false attempt to keep one muscle pulling against the other, the time must come when one of them will " give way." Then we note, in the abnormal case, an abrupt stopping of the tone and we say the **" voice catches."** This manifestation we also hear where an individual is laboring under intense emotional strain, often preliminary to or accompanied by tears. In this latter case we call it a **sob.** The vocal muscles are then entirely out of control, and the individual even has difficulty talking. Stammerers also regularly manifest similar lack of control.

Warning of " Voice Break." But in the *voice break* which takes place while singing, the cessation is not usually carried to quite such an extreme. Usually nature starts with a warning that the control is not just what it should be, and then the **break** we hear is often but a sharp transitory " catch " or cessation of tone; in other cases perhaps but an abrupt alteration of pitch which is almost instantaneously carried back to where it started from. It is not uncommon to hear these *slight breaks* in the singing of even the finest artists, resulting usually from the tension manifest when they are overly tired, or singing under emotional strain of some kind. Providing the artist does not get " panicky " and recognizes the break as a warning that the subtle necessary control has only slipped for the moment, it may not occur again in the whole performance. But if the poise is lost it may result in added interior laryngeal tension of the type we have just been considering; and this may create a consequent " fraying of the nerves " which may well terminate in a complete breakdown before the end of an hour. Then the control is so totally lost as to make any artistic singing really out of the question.

CHAPTER XXVIII

WHAT SHALL STUDENTS OF VOICE BE TAUGHT? — ANY PHYSIOLOGICAL HABITS?

"Learning and teaching to hear is the first task of both pupil and teacher. One is impossible without the other. . . . Even if the pupil unconsciously should produce a flawless tone, it is the teacher's duty to acquaint him clearly with the *causes* of it. It is not enough to sing well; one must also know how one does it. . . .

"False sensations in singing, and disregarded or false ideas of physiological processes cannot immediately be stamped out. A long time is needed for the mind to be able to form a clear image of those processes, and not till then can knowledge and improvement be expected. The teacher must repeatedly explain the physiological processes, the pupil repeatedly disclose every confusion and uncertainty he feels, until the perfect consciousness of his sensations in singing is irrevocably impressed upon his memory, that is, has become a habit. . . . The teacher hears that they are good, so does the public. Only a very few, even among singers, know why . . . I shall be told that tones well sung, even unconsciously, are enough. But that is not true. The least unfavorable circumstance . . . can blow out the 'unconscious' one's light, or at least make it flicker badly. . . .

"The singer is usually worried by the word 'physiology,' but only because he does not clearly understand how to limit his knowledge of it."

LILLI LEHMANN (1924).[1]

So-Called " Good Resonance " or " Voice Placement." The reader will have observed that in the last chapter we distinguished between **nasality, nasal resonance,** and **nasal twang.** The latter, we said, appeared to be traceable primarily to a detestable function of the interior larynx and the first two principally to a function of the nasal passages. At this point scientific study must part company with the imaginary concepts voiced by Miss Lehmann, who talks of " resonance " or " voice placement " as a " focusing of the tone " against the palate, up between the eyes, etc. — a physiological impossibility. Are we the losers by discovering such physiological facts?

The Cause of the Full Penetrating Quality Singers Designate as " Resonant." Good " resonance " implies, rather, a properly produced laryngeal tone. The author believes he has cited enough evidence herein to prove that the ascribing of all those voice qualities heard in so-called

[1] Lehmann, Lilli. *How to Sing*, 3d ed., Macmillan, 1924, pp. 28–33.

" *good resonance* " to a function of the air volume in cavities above the vocal lips or in other words to the " voice and speech resonator " has been very much overdone. Their influence cannot of course be denied. But the effect of the varying involvement of hard and soft surfaces would seem to him of even greater importance. To these he would add a consideration of varying types of tonal quality as produced by the vocal lips or the vibrating medium itself. All of these factors are involved in what is called " good " or " bad voice placement."

No Such Thing as " Placing " a Tone. This idea of telling the voice student to " place the voice up between the eyes," or " against the teeth " or " up in the corner of the room," or " focusing the resonance," etc. has undoubtedly been carried much too far; because none of these expressions represents any of the real facts involved in proper " *tone production*," " *tonal quality*," " *voice placement*," or whatever it may be called.

Use of Actual Fact Descriptions Better. They are but lame substitutes for a lack of knowledge as to what the real cause is, and of a vivid terminology which will state the actual facts in such a way as to aid the student in reproducing the situation called for in order to give that quality. Now and then a student comes along who happens to hit upon the proper " placement " and the teacher says: " Now that is it, put the tone right up there in the corner of the room that way," or uses some other expression of this type until the association between a certain kind of *tonal quality* and that idea serves to remind the student of what he did in order to reproduce it. But we should not deceive ourselves by thinking that the expression itself did anything whatever to aid him in ascertaining how to produce a given *tonal quality*.

Better Knowledge Gives Better Results. If we knew exactly what physiological processes were involved in the production of each type of *tonal quality* — which we do not — then it would be a much easier task to teach the student; our knowledge would undoubtedly result in more successes and fewer failures.

Two Examples. While it is an admirable thing for a natural-born singer to sing beautifully, as it is for a deaf-dumb-blind Helen Keller to be able spontaneously to think beautiful thoughts; it is much better for a mother who knows nothing about the physiological processes involved in speech to be able to teach her deaf-dumb-blind child something of life's artistic processes of expression as well as appreciation. A sing-

ing teacher with but a smattering knowledge of the physiological cause of differences in voice quality might do the same for his pupil. On the other hand, how much more admirable it is for that deaf-dumb-blind child or the voice student to fall into the hands of a teacher who knows the physiology of speech and voice processes well enough to be able to lead them with assurance from out of the realms of darkness. The teacher of the deaf-dumb-blind child should be able to take any other person similarly handicapped, but having a good mentality, and repeat the success as often as such a pupil is brought to her. Yet think of the ages which have passed in which numerous individuals of this kind have lived, achieving but a halting success in mastering simple speech habits, because teachers lacked the necessary information to aid them in other than a perfunctory way. These teachers undoubtedly said in those days there was no help for them since the physiological knowledge of speech was lacking. There are too many teachers of voice who take this same attitude today toward those who are learning how to sing. They expect pupils to learn by mere imitation through processes analogous to those the ordinary mother would use on her deaf child. They realize how few great artists there are in the profession, but they take it for granted that nothing can be done about it. Yet the author is firmly convinced that much of this " mortality " could be prevented as it is now in disease, if we had better voice diagnosticians — if we knew more about the physiological processes involved in producing good "*voice placement*" (or *tonal quality*) — in other words " if the doctor were better prepared " and this he cannot be until we can give him the means of getting that preparation.

Imitation *vs.* the Physiological Approach in Teaching. The author is not advocating any instruction which would make the student constantly conscious of the physiological processes involved in his singing. These are two different questions. The one deals with the knowledge the teacher should have and the other with that of the student. The **teacher must know** these processes, in order to correct the pupil. The time was when we thought a properly directed imitation of a good model would suffice. But no psychologist would now agree with this conception. We know that the ear hears what habit has trained it to hear or a near approximate thereto. Hence no student will hear or can hear what the teacher does until he has been trained to do so; and much of this ear

training will depend finally on his developed ability to reproduce what is to be heard. This means a "cut and try" process repeated until the vocal repetition agrees with the extremely transitory auditory impression, and

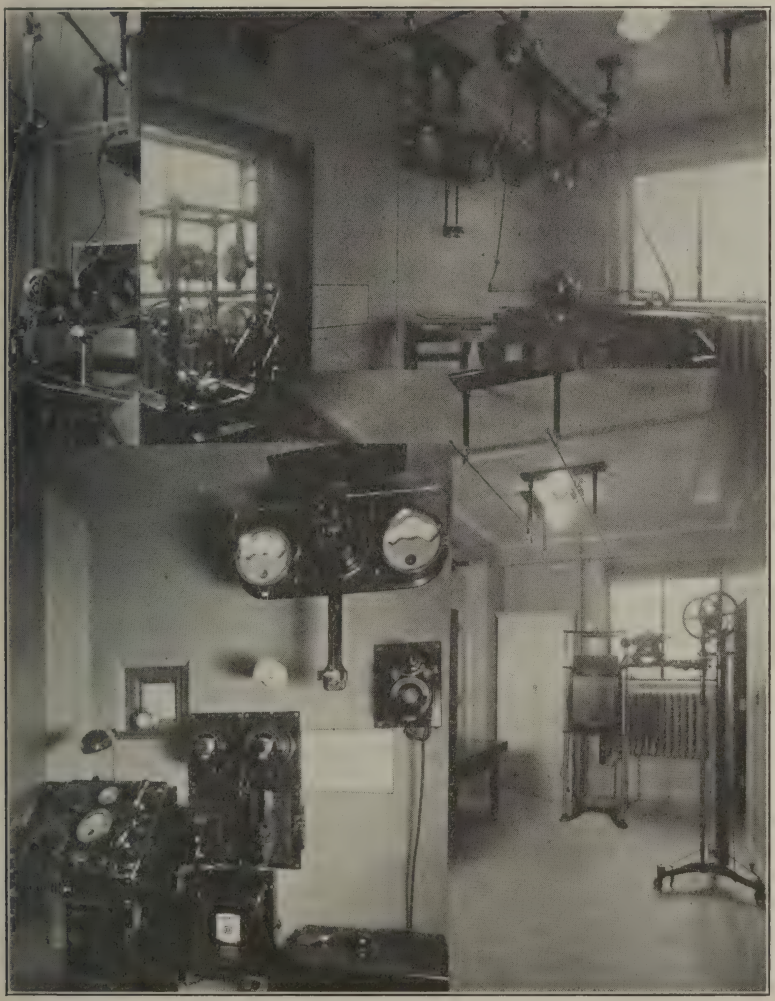


FIG. 217. — A COMPOSITE VIEW OF THE X-RAY LABORATORIES.

then sufficient further repetition to firmly establish the auditory memory in or around Wernicke's Area of the brain, before it can be said that the pupil will thereafter actually "hear" the sound exactly as it is produced.

Evidence that Physiological "Pointers" Teach One "to Hear" So He Can "Imitate." We all have noted how when we have heard a strange foreign sound we try again and again to repeat it before we can assure ourselves as to just what our ears heard. By this same process many a German, for example, hears a sound falsely and of course feels confident he has heard the same sound as was pronounced. You say "*think*" and he hears "*tink.*" So if you rely on pure imitation in order to teach him, you may repeat from now until the end of time: "*no, don't say 'tink,' say 'think' as I do*" and you will find him still shaking his head and replying, "*Dot iss vass I set, I set 'tink' chust like you.*" This conclusion is not based on mere surmise. It rests on laboratory experiments conducted with several thousand foreigners passing through Ellis Island, and a clinical follow-up extending over several years. There cannot be the slightest question of doubt about it. A learner's practice needs to be properly directed by a trained teacher knowing how to utilize certain psychological and physiological controls. So, for example, it comes as a shock to discover what a difference it makes in his ability to "hear correctly" when he is first trained, by telling him to "stick his tongue out under his teeth and blow" before any attempt is made at getting him to hear how the word combination sounds. Often it takes weeks of such physiological exercises before it is psychologically safe to make the transition to actual word combinations or anything with meaning in it that will give him an idea as to what he is working for or what the written symbol may be. For as soon as he suspects what it is, that letter will invariably call up the old false hearing habit; and then he *cannot any longer hear what you want him to hear* until the teacher is again successful in driving the false concept out, and this is then *a much more difficult task than the beginning physiological approach was.* Is he then constantly conscious of the physiological process every time he starts to speak and for all time thereafter? Not at all. Not if the teacher has properly taught him and has been careful to make the new habit agreeable and the old disagreeable. Once habitualized, the physiological process is forgotten, and he speaks with ease as well as correctly; while the untrained learner, on the contrary, speaks with ease but hideously, and will continue to do so without recourse.

Training "Voice Placement" or Tonal Quality. The teaching of proper "placement" or *tonal quality* involves physiological processes

which are new, and hence the overcoming of bad and the mastery of good habits to take their place. It will be seen, therefore, that so far as the actual mechanism and its function in this case is concerned, the problem is analogous and essentially the same, though more complex and difficult than the simple one involved in overcoming the foreign brogue outlined above. For this reason it may be definitely asserted that it will not suffice for any teacher of singing to conduct instruction by purely abstract processes of so-called " spontaneity " or " giving expression to the inborn feeling of beauty " or by saying : " Of course you feel its beauty, just let the tone float out and sing as I do " or " sing like this," etc. — all those who think so to the contrary notwithstanding. For this presupposes the ability of the student with bad hearing habits to change them on demand, and without further ado to proceed to hear as the teacher does. By limiting ourselves to such a conclusion we leave out of consideration the still more vital question as to whether, even if he were able to hear, he would be able to reproduce what he heard without a physiological step by step mastery of the processes by which that is brought about. An argument on this point might be prolonged indefinitely, for it is one of those questions in which mere dogmatic assertion is too likely to assert itself.

Good Models. Of undoubted importance are good models. It would be foolish to deny this fact. Without them the student would find himself in much the same kind of " auditory darkness " as the deaf individual who is forced to master a physiological sound process without hearing control. His instruction would then be about as efficient as a written correspondence school course in singing. But it will not suffice to surround the student with good models and expect him to become like them.

Good Models not Enough. A German surrounded by the good models of native Americans on all sides will still mutilate English after thirty years of conscientious imitation with his : " Yah, I tink dot he vill." And the great majority of Americanization teachers into whose hands he falls will fail to make the correction, for the simple reason that they do not know enough about the physiological processes of speech involved. The training of good quality in singing involves the correction of habits far more vicious and difficult to analyze than these. So until the singing teacher who essays the task has a thorough knowledge of their physiological cause and the processes of correction, you

may be sure that the majority of those students who come to him with the bad voice qualities which are almost universal in humanity at large will be no more successful in becoming masters of the art of artistic singing, than is the average German in mastering his incorrect habits of English pronunciation, either with or without the direction of the average teacher of English we know.

Some Physiological " Pointers " Also of Value to Voice Students. On the other hand, a certain amount of what is good for the master can well be of value to the student as well. For there can surely be no question but that it follows, after what was said above, that the same type of physiological voice " pointers " may quite as advantageously be given the student of voice as would be given the German foreigner. For the foreigner trying to master a new pronunciation and the student of singing struggling to wipe out bad voice quality habits and form correct ones in their stead are not so far apart. The one has to do with qualities in speech and the other with qualities in singing. Both have their origin in the same mechanism, are directed from the same source, and, as has been repeatedly proved herein, are essentially the same. The latter is but more complex, needs finer adjustments, and is coupled with vitally different artistic associations and controls.

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